A COMPREHENSIVE BASIN MANAGEMENT STRATEGY FOR THE ROUGE RIVER WATERSHED

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A COMPREHENSIVE BASIN MANAGEMENT STRATEGY FOR THE ROUGE RIVER WATERSHED

THE ROUGE RIVER VISION

- Recognize that the Rouge River watershed is a component of the larger Great Lakes ecosystem and that watershed management must also benefit the Great Lakes.

- Ensure that one can take pride in the mere existence of the Rouge River watershed -- its system of interconnected waterways and valleys; its source and its lacustrine marsh, woodlands and wetlands; a healthy ecosystem within the most heavily populated metropolitan area in Canada.

- Integrate the mutual benefits of sustainable economic growth and development, and ecological health and quality, within the Rouge River watershed.

- Maintain and enhance the quality of life opportunities provided through public ownership and collective management of the watershed ecosystem.

- *Swim in the Rouge River without becoming infected by disease or soiled by waste films on the water surface.*

- *Eat fish from resident Rouge River populations knowing they are uncontaminated by dangerous chemicals.*

- *Drink from groundwater supplies within the watershed that are free of harmful viruses, protozoa and poison.*

- *Eliminate or minimize the threat of life and property from flooding and erosion within the Rouge River watershed.*

- *Enjoy the beauty of natural aquatic habitats and riverbeds that are uncontaminated by abnormal algal growth and unsoiled by industrial and domestic wastes.*

- *Angle in the Rouge River with some expectations of encountering various preferred species of fish.*

- *Enjoy with pleasure a healthy riverine/valley environment, watching birds, mammals and fish in their natural environment.*

- *Enjoy terrestrial habitats that support sustaining populations of wildlife and waterfowl.*

- *Delight in the enjoyment of clear stream waters (in the seasons when waters should normally be clear) that have no unpleasant odour, abnormal algal growth, or industrial and domestic wastes.*

1.0 PREFACE

The Metropolitan Toronto and Region Conservation Authority (MTRCA, the Authority) is a provincial-municipal partnership established in 1957 under the Conservation Authorities Act to manage the renewable natural resources of the nine watersheds of the Metropolitan Toronto and surrounding area.

The Authority carries out watershed management programs to:

- maintain and improve the quality of the region's lands and waters;
- contribute to public safety from flooding and erosion;
- provide for the acquisition of conservation and hazard lands;
- enhance the quality and variety of life in the community by using its lands for inter-regional outdoor recreation, heritage preservation and conservation education.

In September, 1988, the Authority published Greenspace For the Greater Metro Region, outlining the strategies it intends to follow to carry out these aims. One of these is A Strategy for Watershed Management, which includes the following pertinent objectives:

1. To develop long term management plans for each of the nine watersheds within the Authority's jurisdiction that:
    - recognize the headwaters, rivers and Lake Ontario as distinct but inseparable planning units in ecosystem planning;
    - resolve existing economic and political constraints to existing watershed management through cooperative planning by all agencies;

- o balance ecological health and quality with economic growth and development; and

- o manage our investments of yesterday and plan for our investments and needs of tomorrow.

2. To develop and implement an interim plan of action that will respond to today's water and related land management problems.

3. To monitor, assess, and update on an ongoing basis, the effectiveness of the watershed planning, management, and implementation efforts initiated under the watershed strategy.

A Comprehensive Basin Management Strategy for the Rouge River Watershed (CBMS, the Management Strategy) is the first application of the MTRCA's watershed management strategy to a particular watershed, that of the Rouge River in the east central part of the Metro Region. In fact, the Comprehensive Basin Management Strategy was developed concurrently with the watershed management strategy. This report summarizes the conclusions of the Rouge River Urban Drainage Study, and sets out the Management Strategy itself in the form of policies, technical standards, operational criteria and implementation actions that provincial agencies, municipalities, and all bodies with special interests in the planning of the watershed are able to endorse and implement.

Participation from those municipalities, provincial ministries, public agencies and non-governmental organizations having an interest in the watershed was essential in preparing the CBMS. These agencies and groups are listed below; a more detailed list of the Stakeholders' Committee is found within Appendix 1.

- Ministry of Environment
- Ministry of Natural Resources
- Ministry of Agriculture and Food

- Ministry of Government Services
- City of Scarborough
- Town of Richmond Hill
- Town of Markham
- Town of Pickering
- Town of Whitchurch-Stouffville
- Municipality of Metropolitan Toronto
- Regional Municipality of York
- Urban Development Institute
- Conservation Council of Ontario
- Save the Rouge Valley System
- Toronto Field Naturalists
- Sierra Club of Ontario

This group reviewed the Terms of Reference and commented on the Phase I and II reports of the Rouge River Urban Drainage Study.

The Authority was also assisted by a group of experts in hydrology, fisheries, land use planning, erosion processes, and urban drainage planning and design (Appendix 2).

2.0 INTRODUCTION

2.1 The Watershed

The Rouge River watershed includes the north-eastern sector of Metropolitan Toronto (City of Scarborough), most of the south-eastern quadrant of the Regional Municipality of York (towns of Markham, Whitchurch-Stouffville and Richmond Hill), and a small portion in the west of the Regional Municipality of Durham (Town of Pickering), comprising altogether 320 square kilometres. The principal streams, apart from the Rouge River itself, are Berczy, Bruce and Little Rouge Creeks. All rise in the Oak Ridges Moraine and join to form the boundary between Metropolitan Toronto and Durham before flowing into Lake Ontario.

The watershed consists of four physiographic zones:

- o HEADWATERS: high gradient first and second order streams originating on the Oak Ridges Moraine. Existing land uses are predominantly agriculture, conservation lands and estate residential.

- o MIDREACHES: low gradient second and third order streams flowing across a relatively flat clay plain. Existing land uses are predominantly agriculture and rapidly expanding urbanization.

- o LOWER REACHES: moderate gradient fourth and fifth order streams flowing through deeply incised forested valleys. Existing land uses are predominantly conservation lands and urban development.

- o DELTA MARSH: low gradient fifth order stream flowing through extensive cattail marsh outletting on the shore of Lake Ontario. Existing land uses are predominantly conservation lands and urban development.

Historically, development of the watershed has brought about major changes in the land use characteristics of the basin and the physical and hydraulic characteristics of the watercourse, as a result of forest harvesting, agriculture, urban development, and flood control. Land uses tended to be superimposed upon each other, in the same fashion as urban development is now superimposed on agricultural lands. Human impacts tend to be greatest adjacent to the lake and least in the headwaters, such that some headwater streams still remain relatively undisturbed by human settlement.

The pressures of urban and population growth on the Rouge watershed have not yet been as intense as on other watersheds, for example, the Don River. Nonetheless, with the continuing rapid growth of the region's population, growth pressures within the watershed will continue to intensify. The planning studies of the Rouge River Urban Drainage Study have established and evaluated existing land use and committed land use within the watershed and provided future land use scenarios. These planning studies estimated urbanization would amount to approximately 34% and 41%, respectively, for medium and high growth scenarios and are limited to a planning horizon of 30 years. The recommendations of this strategy are based on a number of assumptions made in the planning studies for the Rouge River Urban Drainage Study which must remain valid; otherwise the strategy, may require rethinking. *Key assumptions included:*

- *York Region growth is dependent on the capacity of the York-Durham sewer system.*

- *The high growth scenario in York Region assumed additional service allocations.*

- *Regional transportation network will be improved by Highway 407 and the East Metro Transportation Corridor.*

- *Development of Federal Government land in Markham, would not occur until after 2010 - 2020 time period.*

2.2 The Context of the Rouge Management Strategy

Watershed management strategies call for watershed management plans to "recognize the headwaters, rivers and Lake Ontario as distinct but inseparable planning units in ecosystem planning". In other words, while the Rouge watershed is a part of a larger ecosystem, it is also an ecosystem itself, in which the natural elements - water, land, wildlife, fish, vegetation - constantly interact not only with each other, but also with human activities and the man-made environment. No single aspect of the watershed can be considered in isolation; each affects and is affected by the others in a continuing, complex, dynamic process. Recognition of this fact is the essential basis of a watershed management strategy.

The M.T.R.C.A.'s 'A Strategy for Watershed Management' recognizes a watershed as an ecosystem and is also the key to achieving the objective of "balanc(ing) ecological health and quality with economic growth and development". This objective is virtually synonymous with "(environmentally) sustainable (economic) development", the central theme of two recent landmark reports: Our Common Future, the report of the (Brundtland) World Commission on Environment and Development, and the report of Canada's National Task Force on Environment and Economy.

Both of these studies, the one global and the other national, reached the same conclusion: that the successful marriage of economic growth with environmental health is the indispensable condition of the future welfare and even the survival of human society. With the state of "the environment" a subject of rapidly growing public concern in Canada and world-wide, the sustainable development idea has attracted widespread and enthusiastic support. The report of the National Task Force has been endorsed by Canada's First Ministers, and in accordance with its recommendations both the Ontario and federal governments have recently established Environment-Economy Round Tables to promote the translation of the concept of sustainable development into reality.

A Comprehensive Basin Management Strategy for the Rouge River Watershed, as one of the first major products of the Authority's watershed management strategy, is therefore extraordinarily timely. In converting the general concept of sustainable development into a comprehensive set of specific, workable, integrated policies and programs, it can be a practical demonstration of the path which must be followed by Ontario, Canada and the world.

3.0 THE ROUGE RIVER URBAN DRAINAGE STUDY

3.1 Background

During the 1970's development pressures in the Rouge watershed increased rapidly, reflected in changes in both municipal planning policies and land use. This created a need for new watershed management programs and techniques. During the same period, important technological advances were made in the field of urban drainage and stormwater management, tending to outstrip progress in policy development, administration and implementation.

The responsibilities of MTRCA and participating agencies with respect to urban drainage planning began to raise a number of questions regarding the success and cost-effectiveness of the techniques then being employed for flood control, erosion control, and addressing urban drainage impacts. Questions also arose with regard to the implementation of environmental safeguards and water quality objectives. Furthermore, it became clear that there was a need to clarify the roles of the various agencies with water management related responsibilities.

Other factors coming into play during the 1980's included:

- growing public concern over the impacts of urbanization on the streams and valley;
- the Ontario Ministry of the Environment's project (Toronto Area Watershed Management Strategy Study - TAWMS) to develop a pollution control strategy for urbanized portions of the Mimico, Humber and Don watersheds (west of the Rouge watershed), involving recognition of the need for a comprehensive watershed based approach to pollution control;
- concern over water quality in Metro, expressed in the formation of the Metro Toronto Water Pollution Committee;

- new technical studies and official guidelines for urban drainage design and stormwater management; and
- new provincial funding for urban drainage projects.

This combination of factors led to two important actions by the MTRCA: adoption of an overall Strategy for Watershed Management, and, in 1986, initiation of the Rouge River Urban Drainage Study (RRUDS, the Study).

3.2 The Study

The broad aim of the RRUDS was to provide a common forum and information sharing network for the various agencies involved in the management of the watershed; to provide a common basis for decision making in the form of a comprehensive data base, reliable state-of-the-art predictive models, and effective mitigative management techniques; and to lay the foundation for coordinated planning, implementation and monitoring in the future.

The specific objectives of the Rouge River Urban Drainage Study were to evaluate existing watershed management practices relating to urban drainage, and to develop and evaluate new practices where warranted, including examination of implementation, cost, and legal considerations. Public participation was a required feature of the Study.

The study used state of the art modelling and assessment techniques and employed experts from the fields of hydrology, erosion processes, water quality and aquatic ecology to complete a series of technical studies describing existing basin characteristics, predicting future changes and examining the effectiveness of current and innovative stormwater practices. The Phase I technical studies have been completed by Marshall, Macklin, Monaghan Ltd., Beak Consultants Ltd. and Walker, Wright, Young and Associates Ltd. and consisted of seven (7) volumes:

- Volume 1: Executive Summary
- Volume 2: Subwatershed Hydrologic Modelling
- Volume 3: Subwatershed Water Quality Modelling
- Volume 4: Subwatershed Runoff Control Study
- Volume 5: Subwatershed Erosion Control Study
- Volume 6: Watershed Water Quality Assessment
- Volume 7: Watershed Environmental Studies

Phase II technical studies were completed by Marshall, Macklin, Monaghan Ltd. and Beak Consultants Ltd. and consisted of five (5) volumes:

- Volume 1: Completion of Subwatershed Studies (channelization and erosion control studies)
- Volume 2: Watershed Wide Studies (hydrology, runoff control, channelization and erosion control studies)
- Volume 3: Flood Control Study - Upper Rouge Study
- Volume 4: Water Quality Study - Phase II
- Volume 5: Environmental Studies Phase II

At the completion of the Phase II technical reports, the MTRCA assembled a Technical Committee comprised of recognized experts in a number of fields. In addition, the Stakeholders Committee comprising those municipalities, provincial agencies and public groups with a mandate and/or an interest in the Rouge Watershed was utilized. Both of these groups assisted the MTRCA in:

- reviewing and qualifying the conclusions of the Rouge River Urban Drainage Study;

- producing a Vision which described in human terms the essential natural features of the Rouge Watershed;

- establishing a number of goals regarding the future use of the Rouge watershed; and
- developing a comprehensive watershed management strategy outlining immediate actions and future requirements.

The qualified conclusions of the Rouge River Urban Drainage Study have been summarized in Appendix 3. These qualified conclusions form the basis on which the Vision and recommended watershed policies were developed.

3.3 Comment

The Rouge River Urban Drainage Study had three innovative features of particular significance.

First, while initiated by the City of Scarborough and Save the Rouge Valley System, and spearheaded by the MTRCA, it was to a large extent a "joint venture" with the active participation of all the principal public agencies with responsibilities relating to Rouge River watershed management.

The second feature was public participation in the Study through membership of public interest groups in the Stakeholders' Committee which monitored it and reviewed its findings.

The third and perhaps most important feature was that the Study embraced the entire watershed as a single physical and ecological unit, a significant departure from the technically and geographically limited approach previously employed.

4.0 THE ROUGE RIVER VISION

4.1 The Vision

Out of the process of collaboration, discussions and debate among the various participants in the Rouge River Urban Drainage Study emerged a "Vision" of the Rouge watershed. The Vision consists of a set of statements defining shared goals for watershed planning and management, goals which are appropriately ambitious but not unrealistic. Collectively, their purpose is to restore and protect the chemical, physical and biological integrity of the Rouge River watershed as a natural resource which provides the setting and foundation for integrated social and economic development.

There are four general vision statements:

- Recognize that the Rouge River watershed is a component of the larger Great Lakes ecosystem and that watershed management must also benefit the Great Lakes.
- Ensure that one can take pride in the mere existence of the Rouge River - its system of interconnected waterways and valleys; its source and its lacustrine marsh; a healthy watershed within the most heavily populated metropolitan area in Canada.
- Integrate the mutual benefits of sustained economic growth and development, and ecological health and quality, within the Rouge River watershed.
- Maintain and enhance the quality of life opportunities provided through public ownership and collective management of the valley system.

5.0 THE MANAGEMENT STRATEGY

5.1 Purpose and Aims

The general Vision statements which emerged from the Urban Drainage Study became the basis of a Comprehensive Basin Management Strategy for the Rouge River watershed, which also was in accordance with the Authority's 'A Strategy for Watershed Management'.

- recognizes the watershed (headwaters, rivers) and Lake Ontario as distinct but inseparable planning units through ecosystem planning;
- attempts to resolve existing economic and political constraints through cooperative planning by stakeholders;
- balances the benefits of ecological health and quality, and economic growth and development;
- manages the watershed community's investments of yesterday and plans for the investments and needs of tomorrow.

In addition to these aims, the following criteria were established by the Authority for the management plan:

- it must establish ambitious yet realistic goals based on ecosystem planning;
- it must be autonomous in that any land uses or land practices must be judged against the overriding goal of protection of the plan;
- it must describe to all stakeholders their role and function in the plan and the importance of implementing the plan as a team;

- it must be a living plan that determines and initiates implementable measures immediately but also provides flexibility for more innovative measures in the future;

- it must be a living plan that can be continually reviewed and revised to ensure that the Vision will be achieved; and

- it must chart a new course for the Rouge watershed away from degradation, towards conservation, enhancement, rehabilitation and restoration. This direction of actions (conservation, enhancement,...) will bring the watershed back to a healthy state and away from existing conditions, and still provide opportunities for sustainable economic growth and development (Figure 1).

A further working objective was to prepare the management strategy in such a way that as far as possible its structure and provisions could readily be adapted to other watersheds.

5.2 Comment

The Rouge River Watershed Management Strategy takes the form of a set of specific Vision statements, technical standards, a set of recommended policies, a set of operational criteria and a set of implementation actions under the headings, in order of priority, of public health, public safety, fisheries, riparian habitat, terrestrial habitat, and aesthetics.

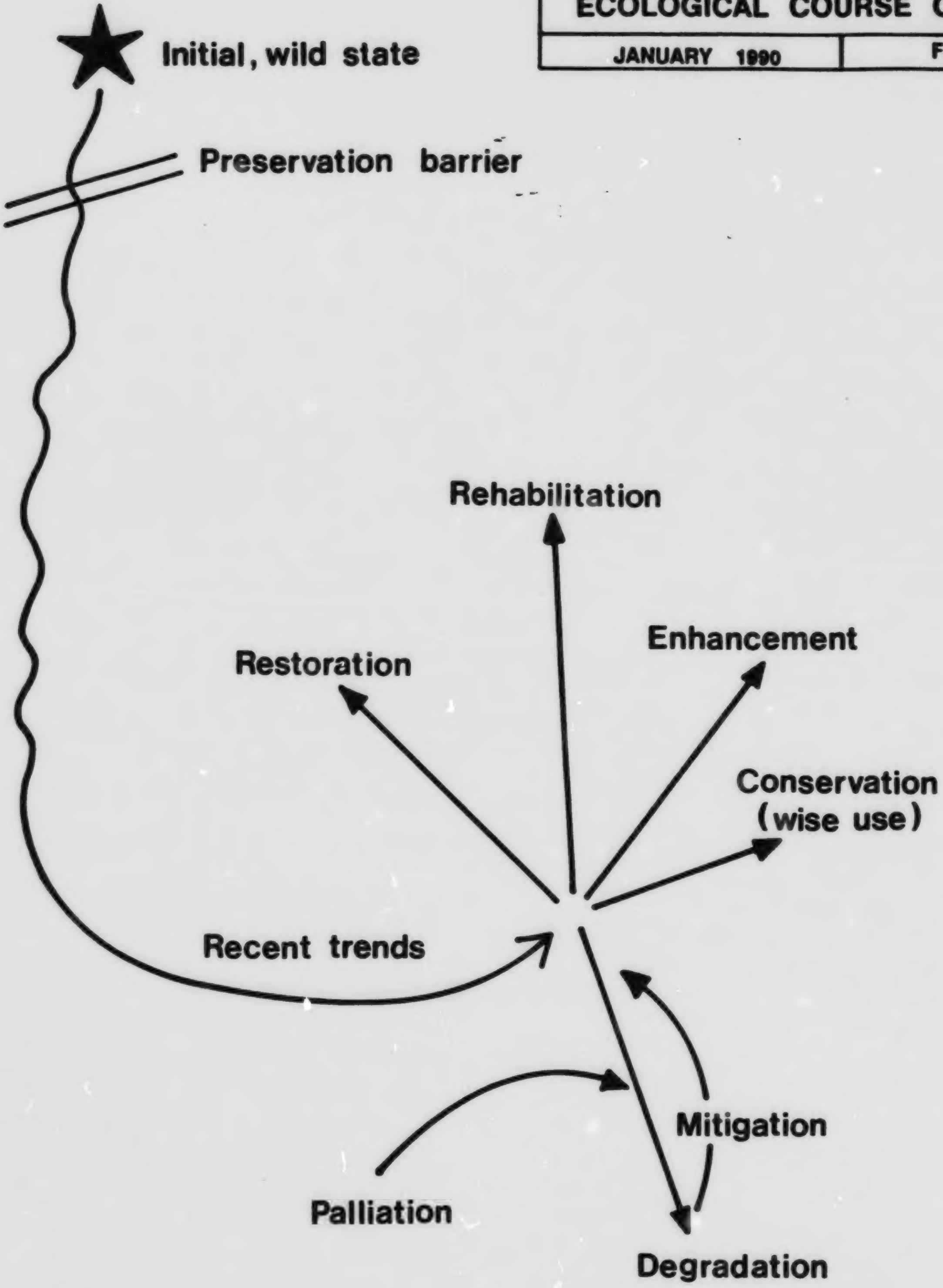
Sections on Fisheries, Riparian Habitats and Terrestrial Habitats do not represent management plans to increase the recreational potential of these natural resources in the watershed, although recreational benefits may accrue as a result of implementation of the policies in these sections. Rather, the policies, guidelines and operational criteria in these sections focus on establishing the healthy natural features of the Rouge ecosystem by identifying target communities and indicator species whose presence as self sustaining populations will provide a barometer of ecosystem health. In order for a species to be an indicator species it must have the characteristics outlined in Table 1.

ROUGE RIVER BASIN
MANAGEMENT STRATEGY

ECOLOGICAL COURSE OF ACTION

JANUARY 1990

FIG. 1


Initial, wild state
Preservation barrier
Rehabilitation
Restoration
Enhancement
Conservation (wise use)
Recent trends
Mitigation
Palliation
Degradation

* Francis, G.R. et al, 1979

TABLE 1

CHARACTERISTICS OF A HEALTHY ECOSYSTEM INDICATOR - EG. AQUATIC (FISH)

- *Resident through its life cycle or for an important component of its life cycle in the ecosystem.*

- *Its habitat requirements should be reasonably well suited to the actual conditions which exist in the river reach being considered.*

- *Sufficient qualitative and quantitative information should be available on its habitat requirements to determine suitability levels for key habitat criteria.*

- *The species should represent a higher trophic level (ie. predator) since these species' habitat needs tend to integrate a broader range of habitat parameters.*

- *Its habitat requirements should be considered generally representative of the needs of associated species in the resident fish community (species guild). If it is one of the more sensitive species, protecting its needs should ensure that the needs of associated species are also met.*

- *It should be a species recognized as having some value (to humans) thus priority in resource management decisions.*

The development of watershed wide management plans in addressing the recreational potential of these resources is recommended as implementation actions. These would be guided by the Comprehensive Basin Management Strategy as well as resource management planning documents such as the Maple District Fisheries Management Plan (MNR 1988).

The recommended policies, operational criteria and implementation actions of the Comprehensive Basin Management Strategy have been further categorized into two sections:

1. Prevention; and
2. Protection and Improvement.

Items under the prevention category would be those policies, operational criteria and implementation actions that are administered through the official plan development process, the urban drainage planning process and plan input and review process. Items for the protection and improvement category would be developed to protect and/or improve the existing resources and are administered through capital works, education programs and/or resource management programs.

The technical standards are the measurables which must be met to fulfil the Vision. These standards are based on existing federal/provincial objectives or guidelines, or Authority objectives. Where standards are not in existence, this document (through discussions with appropriate agencies or leading experts) has suggested appropriate standards.

The recommended watershed policies define the course of actions selected to guide and determine present and future decisions for the management of the Rouge River Watershed.

To set in motion the policies of the strategy, operational criteria have been provided to direct the required actions for the management strategy.

The implementation section is divided into immediate and future actions required for the Rouge River Basin Management Strategy to be successfully carried out. The management actions are further categorized according to lead agency that the strategy is recommending would be responsible for implementation. Participating and supporting agencies and a time frame to initiate the actions are also indicated. These agencies' involvement will include input to the action and may include funding, technical advice and/or in-field implementation.

A number of policies, operational criteria and implementation actions within the main headings of Public Safety and Fisheries have been developed according to a stream level classification system. This classification system was designed corresponding to hydrologic impacts (water level changes affecting flooding and erosion) as determined in the Rouge River Urban Drainage Study, and stream order which reflects fish community distribution. The classification system is described in Table 2. A further division of the stream level classification was necessary for the proposed fisheries as described in Table 2. Figures A-1 and 5, respectively, indicate the hydrologic classification system and the fisheries classification system with regard to the actual watercourses and tributaries of the watershed.

It is MTRCA's objective in floodplain management, as part of its flood control program, to map all watercourses greater than 130 ha and designate them as hazard lands in municipal Official Plans. Land uses are restricted on these lands because of the associated risk to life and property from flooding, and they are normally designated for acquisition by the Authority. As a result, the classification of watercourses as less than or greater than 130 ha has been in common usage in the MTRCA's jurisdiction.

However, flooding and erosion concerns in watercourses less than 130 ha are still addressed through the MTRCA's Stormwater Management Program. Flooding in these small drainage

TABLE 2

WATERCOURSE IMPACT ZONES

STREAM LEVEL (Impact Zones)	FLOOD/EROSION CONTROL	FISHERIES
Level 1 (L-1) (micro system)	-intermittent flows -generally pipes, swales and ditches	-Level 1 -supports downstream fisheries habitat -water quality -temperature -turbidity -dissolved oxygen
Level 2 (L-2) (tributary system)	-defined low-flow channel -continuous flow	-Level 2A Brook Trout (Moraine and Moraine Influenced Watercourses) -Level 2B Bass
Level 3 (L-3) (river system)	-principle watercourse	-Level 3A Bass -Level 3B Rainbow Trout
Level 4 (L-4)	-river mouth influenced by Lake Ontario	-Level 4 -Bass, Pike (Lacustrine Marsh)

areas has generally been regarded as being a municipal drainage responsibility. Key criteria of the program include:

- *requirements for the preparation of master drainage plans, stormwater management plans and erosion and sediment control plans;*
- *the major-minor drainage system philosophy;*
- *zero increase in runoff;*
- *user pay management approach to control runoff impacts at source and avoid the need for downstream remedial works.*

The preparation of master drainage plans and stormwater management plans provides the opportunity to achieve floodplain management objectives on these small drainage areas although they are not designated as flood hazard lands in Official Plans.

The major-minor drainage system has been commonly used to treat flooding and erosion concerns in small drainage areas. The minor or convenience system accommodates the runoff from the more frequent storms up to the design frequency of the system (usually the 2 to 5 year storm). The major system comprises the natural streams and valleys and the man-made streets, swales, channels and ponds and is designed to accommodate flood flows from less frequent events to eliminate or reduce the risk of loss of life and property damage due to flooding.

While the Authority argues for the maintenance of natural floodplains and watercourses or the use of natural channel design if watercourses are altered to facilitate passage of flows, an alternative is to "enclose" the watercourse in a pipe as part of the minor system and convey the major system through streets, easements, etc.

In recent years concerns have been raised regarding the "enclosure" of these small watercourses because of their potential value in providing terrestrial and aquatic habitats, *and aesthetic benefits. In response to these concerns, the CBMS recognizes these watercourses as a special subset of Level 1 and 2 watercourses, and has developed specific policies, guidelines, operation criteria and implementation actions under the headings of Public Safety, Fisheries and Riparian Habitats.*

The following sections outline the Vision, technical standards, recommended policies, operational criteria and implementation actions under each of the main headings. After each main heading, a summary table is provided indicating the Vision, principal policies, implementation actions and time frame.

PUBLIC HEALTH

6.0 PUBLIC HEALTH

6.1 Comment

The Public Health section is primarily concerned with protecting the health of residents and visitors when using the natural resources of the Rouge River Watershed. The Management Strategy considers the end uses of the natural resources as:

- swimming in the Rouge River;
- eating resident fish; and
- drinking groundwater.

The present monitoring data of the Rouge River Study indicates the river system:

- is non-turbid, except in the middle reaches and after rainfall;
- is eutrophic;
- has adequate oxygen resources;
- has moderate levels of bacterial counts; and
- is probably non-toxic (based upon levels of metals).

The focus of this section is on water quantity and quality, and the protection of the aquatic biota.

Primarily, the protection of public health is achieved through the control of sedimentation reaching watercourses. Sediment has many harmful effects including:

- increasing turbidity;
- increasing toxic substances;
- changing the substrate of the stream; and
- introducing nutrients such as phosphates and nitrates, and bacteria.

6.2 Specific Vision Statement

- o Swim in the Rouge River without becoming infected by disease or soiled by waste films on the water surface.
- o Eat fish from resident Rouge River populations knowing they are uncontaminated by dangerous chemicals.
- o Drink from groundwater supplies within the watershed that are free of harmful viruses, protozoa and poison.

6.3 Technical Standards

(a) Swimming

Dry - 100 F.C./100 mls
- Turbidity <50 NTU
- guideline to be assessed within the watercourse

Frequent Rain Event
- up to and including the 3 month rain event
- 100 F.C./100 mls E.M.C. (Event Mean Concentration)
- guideline to be assessed at urban/rural drainage outlets to the watercourse or point discharges and any swimming areas

Infrequent Rain Event
- meet standard of 100 F.C./100 mls 48 hours after rain event
- guideline to be assessed at urban/rural drainage outlets to the watercourse or point discharges and any swimming areas.

(b) Fishing

Fish tissue to meet consumption guidelines (Appendix 4).

(c) Drinking Water

Quality - Follow drinking water guidelines (Appendix 5)

Quantity - Guidelines need to be developed

6.4 Recommended Policies for Public Health

6.4.1 Prevention

(a) Swimming

(i) The Ministry of the Environment's Provincial Water Quality objectives (PWQO) for Swimming and Bathing Use of Water (Appendix 6) should be met throughout the river system during periods of no runoff (dry weather).

(ii) The Ministry of the Environment's PWQO Standards shall be met at swimming areas during frequent summer precipitation events (up to and including the 3 month design storm).

(iii) The Ministry of the Environment's PWQO standards shall be met at swimming areas within 48 hours[1] following infrequent summer precipitation.

(b) Drinking Water

(i) The Ministry of the Environment's Drinking Water Objectives shall be met for existing municipal and private drinking uses for groundwater (Appendix 5).

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[1] 48 hours is considered a reasonable period to allow passage of contaminated flows and settling of sediments.

(ii) The existing groundwater drinking supplies for municipal and private uses shall be maintained wherever possible; given that other uses such as for stream baseflow should not be compromised.

(c) Toxins

(i) The levels of metals, pesticides, and other organic chemicals in tissues of resident Rouge River fish shall not result in human consumption restrictions or cause increased exposure to transmittable disease, parasites and/or viruses (Appendix 4).

(d) Chemical Spills

(i) The occurrence and discharge to drainage systems of all spills shall be minimized.

6.4.2 Protection and Improvement

The following recommended policies are identical as stated for the prevention component of the Public Health section. They are repeated in the protection and improvement component, as implementation of remedial and/or resource management programs, can also meet these same policies.

(a) Swimming

(i) The Ministry of the Environment's Provincial Water quality Objectives (PWQO) for Swimming and Bathing Use of Water (Appendix 6) should be met throughout the river system during periods of no runoff (dry weather).

(ii) The Ministry of the Environment's PWQO Standards shall be met at swimming areas during frequent summer precipitation events (up to and including the 3 month design storm).

(iii) The Ministry of the Environment's PWQO Standards shall be met at swimming areas within 48 hours following infrequent summer precipitation.

(b) Chemical Spills

(i) The occurrence and discharge to drainage systems of all spills shall be minimized.

6.5 Operational Criteria for Public Health

6.5.1 Prevention

(a) The preparation of an erosion-sediment control plan shall include mechanisms designed to ensure on site sediment control during active construction. Such mechanisms could include but not necessarily be limited to the following:

- temporary vegetation of stock-piled earth and exposed construction sites;

- retention of vegetation buffer strips;

- diversion ditches for runoff;

- sediment traps, basins and ponds;

- temporary discharge contouring; and

- infiltration trenches and galleys.

NOTE: Operational criteria are required for retention and spill control ponds, natural channels, groundwater quantity and quality and resource guidelines for master drainage plans. Resource guidelines would deal with:

- fisheries;
- riparian habitat;
- terrestrial habitat; and
- aesthetics.

Certain related implementation actions (Section 6.6) will assist in the preparation of these operational criteria. The need for resource guidelines for master drainage plans is discussed in the Public Safety section (Section 7.6).

6.5.2 Protection and Improvement

(a) The preparation of a municipal spill action program should follow the procedures and responsibilities as outlined by the Ministry of Environment's Province of Ontario Contingency Plan for Spills of Oil and Other Hazardous Materials.

(b) Municipal maintenance and/or enforcement programs should be followed.

(c) The preparation of farm remedial plans should include mechanisms designed to eliminate and/or minimize bacteria sources to watercourses. Such mechanisms could include but not necessarily be limited to the following:

o fence pastures to control all livestock from direct access to watercourses and drainage ditches;

o use alternate watering sources such as:
  - well water
  - indirect stream watering;

o all milkhouse washwater be treated or discharged to manure storage system;

- o divert rainfall and snowmelt from barnyards and manure storage by:
  - eavestroughing structures
  - utilizing ditches, berms and drains
  - constructing retaining wall around barnyard and manure storage and direct to storage tank;

- o incorporate manure within 24 hours after spreading and avoid spreading within 10 metres of watercourses;

- o ensure all farmhouses have properly operating sewage systems; and

- o *ensure adequate storage and containment for manure storage facilities.*

6.6 Implementation of Public Health Policies

(a) Prevention - Immediate Action

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority/Local Municipalities

Participating and Supporting Agencies: Regional Municipalities
MOE
MNR

Time Frame: Initiate within 1 year and thereafter, ongoing

Expand MTRCA and municipal enforcement programs to ensure that erosion and sediment control plans are properly designed, implemented, maintained and removed.

(ii) Lead Agency: The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies:
MOE
MNR
Local Municipalities,
Urban Development Institute
Non-governmental Organizations.

Time Frame: Initiate within 1 year and ongoing for 2 to 3 years

Establish a pilot project to investigate design criteria, guidelines and effectiveness of water quality ponds and other control measures such as infiltration trenches and galleries and soak-away pits. This project would be a joint venture of a number of agencies and relevant non-governmental organizations.

The project results will assist in the design of control measures effective in improving water quality.

(iii) Lead Agency: Local/Regional Municipalities

Time Frame: Continue in 1990 and thereafter, ongoing

Ensure all new industrial/commercial developments are designed with retention ponds (equipped with skimmers/separator) to function as the final control measures for spills.

(b) Prevention - Future Actions

(i) Lead Agency: Ministry of the Environment

Participating and Supporting Agencies: MTRCA, MNR, MOH

Time Frame: Initiate in 1990 for 2 to 3 years

Undertake additional studies to assist the development of policies and operational criteria to be implemented in the plan input and review process and to address deficiencies in the present modelling and a monitoring data base. These studies include:

(a) groundwater quality and quantity in the watershed;

(b) monitoring data deficiencies:
  o assessment of synthetic organic chemicals (SOC's) in the Rouge River system;

  o measurement of sediment contaminant concentrations;

  o measurement of fish contaminant levels;

  o leachate quality from waste management sites; and

  o toxicity monitoring.

(c) Protection and Improvement - Immediate Actions

(i) **Lead Agencies:** Ministries of the Environment and Agriculture and Food

Participating and Supporting Agencies: MTRCA
Local Municipalities

Time Frame: Initiate within 1 year

Extend existing provincial programs under a cooperative "Rouge River Farm Remedial Program" to eliminate and/or control bacteria sources from manure storage, livestock access to watercourses or other agricultural practices. These programs include:

- Rural Beaches Farm Remedial Plans (Clean Up Rural Beaches - CURB);

- Ontario Soil Conservation and Environmental Protection Program II (OSCEPAP);

- land stewardship program.

This recommended Remedial Program should concentrate its efforts on watercourse fencing (access control), stream plantings, farm remedial plans and improved manure storage.

(ii) **Lead Agency:** Local/Regional Municipalities

Time Frame: Continue in 1990 and thereafter, ongoing

Maintain and/or increase existing municipal maintenance/enforcement programs to eliminate and/or control bacteria sources. These programs would include:

- By-Law Enforcement
- existing plumbing testing and inspection programs
- existing sewer use by-law enforcement
- pet litter control
- street sweeping
- catch basin cleaning

(iii) **Lead Agency:** Local/Regional Municipalities

Participating and Supporting Agency: MOE

Time Frame: Continue in 1990 and thereafter, ongoing

Maintain and/or extend municipal spill action control programs. Extension of programs could include:

(a) Simultaneous arrival time of municipal works department (or appropriate department), fire department and Ministry of the Environment (Spill Management Team - where required at the spill location).

(b) Changes in spill control practices (if required):
o education;
o protocol for handling different types of spills;
o use of sorbants; and
o collection of spillage/sorbants and treatment.

(c) Installation of API type, oil-water separators upon catchbasins draining the areas of petrochemical industry.

(d) Inspection of industries to ensure that floor drains receiving spillage pollutants from normal practices are either connected to the sanitary sewer system or lead to a water treatment system before discharge.

(e) Installation of storm drainage for gas stations and garages to include provisions for "first flush" to be routed to sanitary sewer system.

(iv) ***Lead Agency:*** *Local/Regional Municipalities.*

Time Frame: Initiate in 1990.

(a) Modify existing road maintenance and Parks and Recreation practices to minimize impact on water quality by the reduction or elimination of the use of pesticides, herbicides, fertilizers, road salt, etc.

(d) Protection and Improvement - Future Action

(i) **Lead Agency:** Local/Regional Municipalities

Participating and Supporting Agencies: MOE
Non-governmental Organizations.

Time Frame: Initiate in 1990

Establish a public education and awareness program to outline the benefits of "good housekeeping" practices such as:

- poop and scoop;
- litter control;
- household hazardous waste program.
- *gardening and lawn care alternatives (chemicals/composting).*

NOTE: This public education and awareness program should be consistent with and coordinated with public education and awareness programs in the other sections of the Comprehensive Basin Management Strategy.

TABLE 3

PUBLIC HEALTH

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- swim without becoming infected by disease - eat resident fish uncontaminated by dangerous chemicals - drink groundwater free of harmful viruses, protozoa and poison	- MOE's PWQO met during dry weather, throughout the river - MOE's PWQO met during frequent summer precipitation events, at swimming areas - MOE's PWQO met within 48 hours following infrequent summer precipitation, at swimming areas - MOE's PWQO met for existing municipal and private groundwater drinking sources - minimize occurrence and discharge of spills to drainage systems	Lead Agencies - MTRCA, Local Mun. Participatory Agencies -MNR, MOE, Reg. Mun. - expand enforcement programs to ensure design, implementation and maintenance of erosion and sediment control plans	1 year to initiate and ongoing
		Lead Agency - MTRCA Participatory Agencies - MOE, MNR, Local Mun., UDI - undertake cooperative pilot project to investigate effectiveness of wet ponds for quality control	1 year to initiate and ongoing 2-3 years
		Lead Agency - MOE Participatory Agencies - MTRCA, MNR, MOH - additional studies required to aid development of policies and operational criteria	Initiate 1990 and 2-3 year ongoing
		Lead Agencies - Local/Reg. Mun. - design wet ponds in new industrial/commercial developments to act as final control for spills	Continue in 1990 and ongoing
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- MOE's PWQO met during dry weather, throughout the river - MOE's PWQO met during frequent summer precipitation events, at swimming areas - MOE's PWQO met within 48 hours following infrequent summer precipitation at swimming areas - minimize occurrence and discharge of spills to drainage systems	Lead Agencies - MOE, OMAF Participatory Agency - MTRCA - extend existing provincial programs under a cooperative "Rouge River Farm Remedial Program"	1 year to initiate
		Lead Agencies - Local/Reg. Mun. Participatory Agency - MOE - maintain/extend municipal spills action control programs	Continue in 1990 and ongoing

PUBLIC SAFETY
FLOOD CONTROL

7.0 PUBLIC SAFETY - FLOOD CONTROL

7.1 Comment

It is the MTRCA's mandate as a watershed manager to minimize the threat to life and property as a result of flooding. To fulfil this mandate, the Authority has identified and inventoried numerous flood susceptible sites on the Rouge River, and has developed and implemented a flood control policy for its entire jurisdiction.

One of the objectives of the Rouge River Urban Drainage Study was to evaluate the MTRCA's current policy for runoff control as it relates to flood control on the Rouge River for both technical effectiveness and cost effectiveness.

The conclusions from this portion of the Urban Drainage Study are as follows:

(i) The Rouge River watershed may be considered in terms of four hydrologic impact zones (Table 1):

  (a) Level 1 (L-1) - micro-system
  These watercourses generally are pipes, swales and ditches, and are characterized by intermittent flows.

  (b) Level 2 (L-2) - tributary system
  These watercourses can be 1st, 2nd or 3rd order streams and are characterized by a defined low-flow channel and continuous flows.

  (c) Level 3 (L-3) - river system
  These watercourses are generally 4th and 5th order streams and up, and are considered the principal watercourses in a watershed.

(d) Level 4 (L-4) - lacustrine marsh

This watercourse is part of a Lake Ontario waterfront marsh and is substantially influenced by lake level fluctuations.

(ii) The effectiveness of runoff control can also be discussed in terms of stream levels.

(a) Level 1

The study showed that runoff controls can effectively control all peak flows for Level 1 streams to pre-development levels.

(b) Level 2

The study showed that runoff control implemented on Level 1 streams does not ensure that control will be achieved on downstream Level 2 streams due to changes in the timing of flows.

The Rouge Study results showed that runoff control for Level 2 streams can be effective if it is designed on subwatershed basis.

(c) Level 3 and 4

The study showed that stream runoff control is not effective in controlling 2 year and 100 year flows in Level 3 and 4 streams.

The generally accepted practice of designing upstream runoff control facilities to achieve zero increase in downstream peak flows is not effective for Level 3 and 4 streams.

(iii) The study demonstrated that extensive channelization utilizing a traditional trapezoidal design can increase peak flows for all storms due to reduced travel times regardless of upstream runoff control measures.

7.2 Specific Vision Statement

- o Eliminate or minimize the threat to life and property from flooding and erosion within the Rouge River watershed.

7.3 Technical Standard

The flood standard for regulatory purposes within the Rouge River watershed is the Regional Flood (Hurricane Hazel, 1954) or the 100 year flood, whichever is greater, pursuant to the Provincial Flood Plain Planning Policy Statement (October, 1988).

7.4. Recommended Policies for Public Safety (Flood Control)

(a) The prevention of new flood susceptible development is achieved both through the administration of Ontario Regulation 293/86 (as defined within the Conservation Authorities Act) and through the plan input and review process. In this regard, existing policies and operational criteria have been successfully implemented and generally have widespread support and acceptance.

The creation of new flood susceptible sites within the Rouge River watershed shall be minimized through a program of development control and acquisition.

In the past, the protection of existing flood susceptible development has been addressed through a combination of runoff control (stormwater management techniques, implemented through the plan input and review process) and remedial works.

The study results demonstrate a "blanket" policy of runoff control for flood control purposes is not effective on a watershed basis.

The effectiveness of runoff control can be discussed in terms of stream levels. Flood control policies regarding runoff control shall be stream level specific (Table 4):

i) Level 1 Streams (L-1)

Urbanization causes large percentage increases in flows in L-1 streams, however, the absolute magnitude of the flows is still small.

The hydrologic impacts on L-1 streams become significant only in terms of the potential cumulative impacts on L-2 and L-3 streams.

Therefore: Flood Control requirements for Level 1 streams shall be assessed based on the downstream flood hazard.

ii) Level 2 Streams (L-2)

This is the first level where the cumulative effects of land use changes are felt.

The most significant increases in flows from changing land use are felt on L-2 streams.

The Rouge Study results demonstrate that runoff control ponds can be an effective flood control technique when draining to L-2 streams if it is designed on a subwatershed basis.

Therefore: Flood Control requirements shall be assessed based on the downstream flood hazard.

TABLE 4

SUMMARY OF RUNOFF CONTROL REQUIREMENTS

STREAM LEVEL	FLOOD CONTROL POLICIES	OPERATIONAL CRITERIA
L-1	- runoff control may be required depending on downstream flood hazards on L-2 streams	- MDP to be prepared - OR - - SWMP to be prepared with contribution to MDP
	- runoff control not required when outletting directly to L-3 streams	- SWMP to be prepared, plus contribution to downstream (L-3) remedial works and/or acquisition
L-2	- runoff control may be required when draining to L-2 streams	- MDP to be prepared - OR - - SWMP to be prepared with contribution to MDP
	- runoff control not required when draining directly to L-3 streams	- SWM to be prepared, plus contribution to downstream remedial works and/or acquisition
L-3, L-4	- runoff control not required when draining directly to L-3 and L-4 streams	- SWMP to be prepared, plus contribution to downstream (L-3) remedial works and/or acquisition

iii) Level 3 and 4 Streams (L-3, L-4)

In L-3 and L-4 streams, the percentage increases in flow are less than L-1 and L-2 streams. The cumulative effects of upstream land use changes are increasingly "dampened out" as total developed upstream drainage area increases.

The Rouge Study results demonstrate that upstream runoff control is not effective in controlling flood levels in L-3 and L-4 streams.

Large on-line centralized storage facilities (flood control dams) may be effective in controlling flood levels in L-3 and L-4 streams. Dams for flood control may be reviewed and considered along with other remedial works options.

Therefore: In lieu of effective runoff control, flood control requirements on Level 3 and 4 streams shall be addressed through the protective component.

(b) *Protection and Improvement*

Existing development, land and terrestrial resources shall be protected through the implementation of a remedial works and acquisition program.

7.5 Operational Criteria for Public Safety (Flood Control)

(a) Flood Control - Prevention

i) All Level 1, 2 and 3 streams that drain in excess of 130 ha shall have an "Open Space - Hazard Land" designation in all local and regional municipal Official Plans.

ii) A one-zone approach to floodplain management shall continue to be implemented. Local and regional municipalities shall incorporate appropriate statements and designations concerning flood hazard areas in Official Plans and secondary plans (or their equivalent), and restrict development in such flood hazard areas through the enactment of restricted area by-laws (zoning) and/or development control by-laws, and identify flood hazard lands as lands intended for public acquisition.

iii) Limited compatible uses shall continue to be permitted in the floodplain pursuant to MTRCA floodplain planning policies for Undeveloped Floodplains (1980) and Parking Lot Policy (1985).

iv) In areas where existing development is subject to flooding, all development/redevelopment applications shall be reviewed based on the Authority's current floodplain planning policies for Undeveloped Floodplains (1989), and Flood Susceptible Sites Policy (1987), and the Provincial Floodplain Planning Policy Statement (1988) and supporting guideline documents.

v) Channelization to facilitate new development shall only be considered where there is no feasible alternative and:

- in the context of a master drainage plan;
- in ill-defined floodplains;
- where there are no other prohibitive resource-related concerns;
- utilizing natural channel design in accordance with the policies of the fisheries and riparian habitat sections.

vi) Traditional channel design shall be permitted within existing development areas only, if there is no other flood control option.

vii) Level 1 Stream Drainage

(a) Level 1 Draining to Level 2

Master Drainage Plans shall be prepared prior to development, or a stormwater management plan shall be prepared with a contribution to the preparation of a future Master Drainage Plan.

MTRCA and municipality to determine which of the two options would be appropriate based on the time frame and implementation of a Master Drainage Plan.

(b) Level 1 Draining to Level 3

Stormwater Management Plan to be prepared prior to development, plus contribution to downstream works and/or acquisition.

viii) Level 2 Stream Drainage

(a) Level 2 Draining to Level 2 Streams

Master Drainage Plans shall be prepared prior to development, or a stormwater management plan shall be prepared with a contribution to the preparation of a future Master Drainage Plan.

(b) Level 2 Draining to Level 3 Streams

Stormwater Management Plans shall be prepared prior to development, plus contribution to downstream works and/or acquisition.

ix) Level 3 Stream Drainage

(a) Level 3 Draining to Level 3 or 4 Streams

Stormwater management plan shall be prepared prior to development, plus contribution to downstream works and/or acquisition.

(b) Flood Control - Protection and Improvement

i) The Authority shall continue to carry out flood control works under its existing Flood Control Program. In addition, a program of remedial works and/or acquisition shall be undertaken on Level 3 streams in lieu of effective runoff control. This additional program will also apply to Level 2 streams where MDP have not been implemented.

ii) Runoff control and protective works shall also provide benefits to fisheries, riparian and terrestrial habitats where feasible.

7.6 Implementation of Public Safety (Flood Control) Policies

(a) Prevention - Immediate Action

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Time Frame: Initiate within 1 year

Extend floodline mapping to the 130 ha drainage limit for all Level 1 and/or Level 2 streams and identify any additional flood susceptible sites; also extend fill line mapping for regulation purposes.

(ii) **Lead Agency:** Local/Regional Municipalities

Time Frame: Initiate within 1 year

Ensure appropriate "Open Space - Hazard Land" designations and policy statement are contained in local and regional municipal Official Plans and secondary plans and that area bylaws are updated to incorporate these designations and policy statements.

(iii) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agency: Local Municipality

Time Frame: Initiate in 1990

Expand MTRCA and municipal enforcement programs to ensure compliance with development control and fill regulations, both during and after construction.

(iv) **Lead Agencies:** The Metropolitan Toronto and Region Conservation Authority and Local/Regional Municipalities

Time Frame: Initiate within 1 year

Delineate Master Drainage Plan areas on a 1:10000 map base and incorporate them into municipal planning documents.

Establish a time frame/implementation plan for Master Drainage Plan preparation for Level 2 watercourses.

Establish funding mechanisms for flood control works and an acquisition program for flood susceptible sites on Level 3 streams to be implemented in lieu of upstream runoff control.

(v) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: MNR
MOE

Time Frame: Initiate within 1 year.

Prepare generic terms of reference for Master Drainage Plan studies to ensure consistency within the Rouge Study methodology and resultings including the preparation of guidelines for:

- flood control
- erosion control
- water quality
- riparian habitat
- terrestrial habitat
- fisheries
- aesthetics
- natural channel design

These terms of reference shall also apply to stormwater management plans where there are no master drainage plans.

(vi) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Time Frame: Initiate within 1 year

Establish a hydrologic model maintenance program that includes: staff training, model adjustment and updating.

(b) Prevention - Future Actions

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: Local/Regional Municipality

Time Frame: Initiate within 1 year and then, ongoing.

Accelerate acquisition programs for public ownership of hazard lands.

(ii) ***Lead Agency:*** *The Metropolitan Toronto and Region Conservation Authority*

Participating and Supporting Agencies: *MNR*
MOE
WSC (Water Survey of Canada)

Time Frame: *Initiate within 1 year.*

Develop an enhanced data gathering Network Plan for the Rouge watershed incorporating both precipitation and stream gauging for use in all aspects of water management.

(iii) ***Lead Agency:*** *The Metropolitan Toronto and Region Conservation Authority*

Time Frame: *Immediate and continuous.*

Utilize the Rouge Hydrologic Model to maintain an up-to-date representative model of development on the Rouge River watershed.

(c) Protection and Improvement - Immediate Action

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: Local/Regional Municipalities.

Time Frame: Initiate within 1 year.

Develop a program of remedial works and acquisition for the flood susceptible section of Unionville. The remedial works component of the program shall be administered by the MTRCA through its Flood Control Program. The acquisition component of the program shall be administered jointly by the MTRCA and the municipality.

Develop an acquisition plan for flood susceptible sites on Level 3 streams. This plan should include:

- priority for acquisition
- ownership/responsibility
- estimated costs
- implementation strategy
- administration.

(d) Protection and Improvement - Future Actions

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: Local/Regional Municipalities
MNR

Time Frame: Initiate in 1990

Establish a public education program to increase public awareness of floodplain management and flood and erosion control objectives.

TABLE 5

PUBLIC SAFETY
FLOOD CONTROL

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- eliminate or minimize the threat to life and property from flooding and erosion within the Rouge River Watershed	- creation of new flood susceptible sites shall be minimized	Lead Agency - MTRCA - extend floodline mapping to 130 ha drainage limit on Level 1 and 2 streams	1 year to initiate
	Level 1 Draining to Level 2 Streams - runoff control may be required, depending on downstream flood hazards on Level 2 streams	Lead Agency - MTRCA Participatory Agencies - Local/Reg. Mun. - expand enforcement programs to ensure development control and fill regulation	1 year to initiate and ongoing
	Level 1 Draining to Level 3 Streams - runoff control not required when outletting directly to Level 3 streams	Lead Agencies - MTRCA, Local/Reg. Mun. - delineate MDP areas on a 1:10,000 map base - establish funding mechanisms for flood control works and acquisition programs for flood susceptible sites on Level 3 in lieu of runoff control	1 year to initiate
	Level 2 Draining to Level 2 Streams - runoff control may be required when draining to Level 2 streams	Lead Agency - MTRCA Participatory Agencies - MOE, MNR - prepare generic terms of reference for MDP studies including resource guidelines	1 year to initiate
	Level 2 Draining to Level 3 Streams - runoff control not required when draining directly to Level 3 streams	Lead Agency - MTRCA - establish hydrologic model maintenance program	1 year to initiate
	Level 3 Draining to Level 3 Streams - runoff control not required when draining directly to Level 3 streams		
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- protect existing development, land and terrestrial resources through remedial works and acquisition program	Lead Agency - MTRCA Participatory Agencies - Local/Reg. Mun. - develop a program of remedial works and acquisition for the flood susceptible section of Unionville	1 year to initiate

PUBLIC SAFETY
EROSION CONTROL

8.0 PUBLIC SAFETY - EROSION CONTROL

8.1 Comment

Generally, erosion hazard as it relates to public safety is a function of the measured distance from the physical erosion problem to a structure(s) and associated usable property. Typically, erosion problems within the Rouge River watershed are related to riverbank erosion and/or slope instability.

The MTRCA developed an erosion control program of prevention, and protection and improvement to address the public safety issue. The prevention component addressed the assumed negative impacts of urbanization through the plan input and review process which includes stormwater management and also through the administration of the Authority's regulations (Ont. Reg. 293/86). The protection component addressed existing erosion problems through the implementation of a remedial works program on watercourses generally in excess of 1300 hectares.

The purpose of the erosion component of the Rouge River Urban Drainage Study was to determine and comprehend more thoroughly the effects of urbanization on channel erosion, and to determine the effectiveness of the Authority's storm water management policy (re: runoff control ponds) to control erosion in downstream watercourses.

The study demonstrated that urban hydrology changes can aggravate or accelerate erosion, however, the rate of erosion is site specific and dependent on a number of variables. The study also indicated that *duration and volume of flow is as important as peak flow in increasing erosion potential and that existing stormwater management practices appear to be ineffective in reducing the erosion potential when runoff peak is controlled to predevelopment levels. It is also recognized that achieving "zero volume increase" was not feasible. Therefore it was felt that the Authority's current "blanket" storm water management policy for erosion control may not always be effective and should discontinued. In its place the strategy is recommending that erosion control studies be carried out at the MDP level to* *determine the most effective means to control erosion on Level 1 and 2 streams. This may take the form of local control, downstream channel works or a combination thereof.*

The flood control component of the study demonstrated that stream runoff control is not effective in controlling 2 year and 100 year flows in Level 3 and 4 streams; therefore, it is implied that runoff controls are also not effective for erosion control. Therefore, in addition to the Authority's existing remedial works program and in lieu of effective runoff control, a funding mechanism should be developed whereby the MTRCA can collect and administer funds for remedial works and acquisition on Level 3 streams.

Finally, there is recognition that development limits (set backs) provide the best opportunity to prevent new erosion prone development from occurring.

8.2 Specific Vision Statement

Eliminate or minimize the threat to life and property from flooding and erosion within the Rouge River watershed.

8.3 Technical Standards

Development adjacent to rivers/valleys is to be safe from erosion during its life which the Authority assumes to be 100 years. Safety from erosion is a function of long term stable slopes and/or erosion rates.

8.4 Recommended Policies for Public Safety (Erosion Control)

(a) Prevention

Prevent the creation of new erosion prone development and minimize the negative impacts associated with new development through the enforcement of the Authority's regulations (293/86), the adoption of appropriate development controls under the Planning Act, and participation in the municipal plan input and review process.

(b) Erosion Control - Protection and Improvement

Existing development, land, and terrestrial resources shall be protected through the implementation of a remedial works and acquisition program.

8.5 Operational Criteria for Public Safety (Erosion Control)

(a) Prevention

(i) Erosion studies shall be undertaken as part of the Master Drainage Plan/Stormwater Management Plan process on Level 1 and 2 watercourses to determine the most effective means of control.

(ii) Development limits (rear property line) for new development tributary to watercourses draining more than the 130 ha shall be determined as follows:

(a) Stable Defined Valley

A minimum of 10 metres back from the top of bank (Figure 2).

(b) Unstable, Defined Valley

A minimum of 10 metres back from a projected 2H:1V slope or stable slope line as determined through a geotechnical study; whichever is greater (Figure 3).

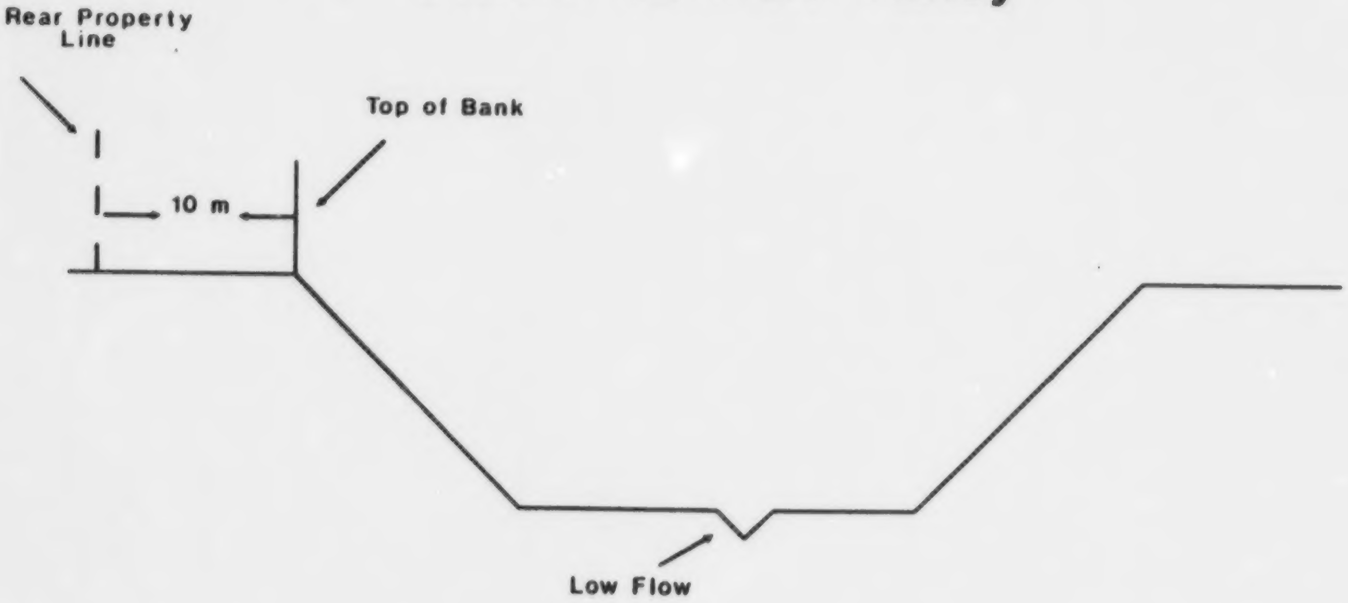
(c) Ill-Defined Valley

A minimum of 10 metres back from the Regional Storm Floodline (Figure 4).

New development can be grouped into four major categories, as described in the following:

1) new multi-lot or large lot development;
   . structures proposed for previously undeveloped areas (large-scale).

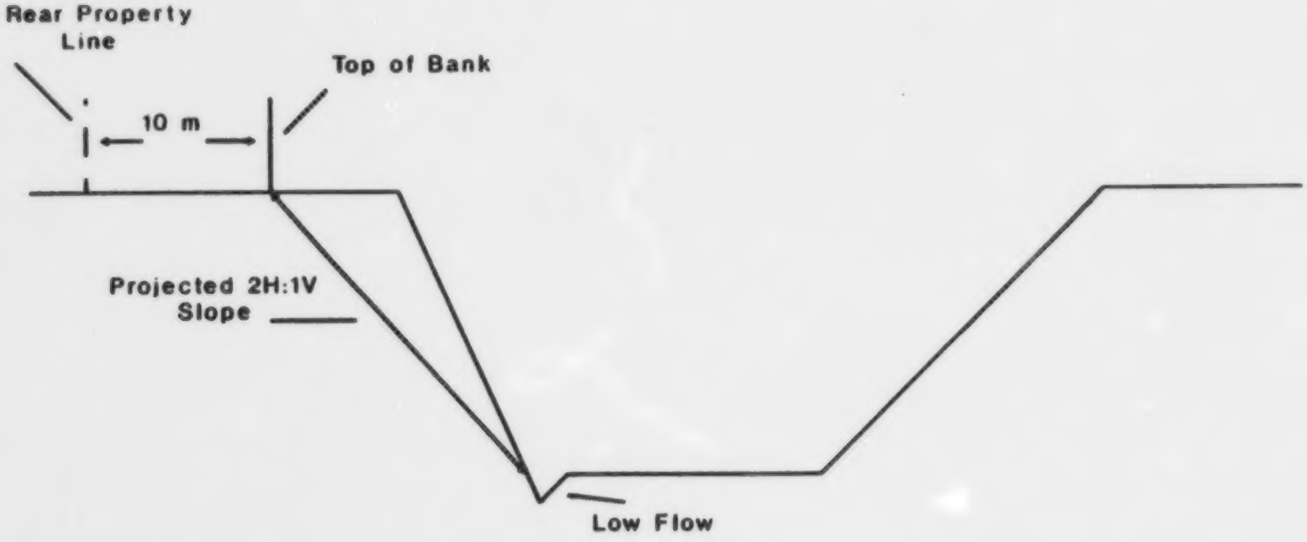
Stable defined valley


Rear Property Line
Top of Bank
10 m
Low Flow

Development Limit: A minimum of 10 metres back from the top of bank.

Figure 2

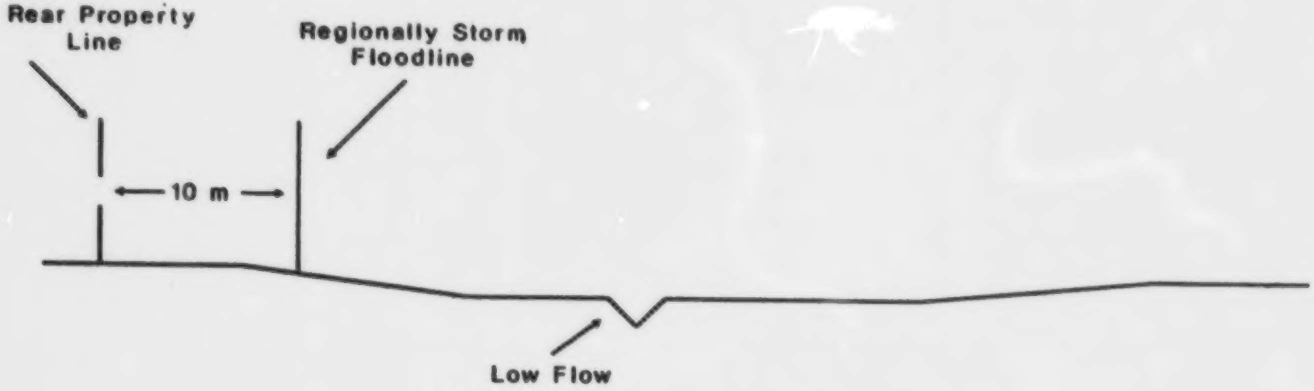
Unstable, defined valley


Rear Property Line
Top of Bank
10 m
Projected 2H:1V Slope
Low Flow

Development Limit: A minimum of 10 metres back from a projected 2H:1V slope or stable slopes as determined through a geotechnical study; whichever is greater.

Figure 3

Ill-defined valley


Rear Property Line
Regionally Storm Floodline
10 m
Low Flow

Development Limit: A minimum of 10 metres back from the Regional Storm Floodline.

Figure 4

2) major redevelopment or infilling;
   - development which is at a large enough scale where, generally, conformity with surrounding areas is not necessarily critical.

3) infilling, replacement, major additions;
   - infilling - development on previously undeveloped lots, generally bounded by existing development on adjacent sides; *development may be permitted to match existing similar development on adjacent sides subject to satisfying geotechnical concerns;*

   - replacement - existing structure removed and new structure erected;

   - major additions/alterations - construction is equal to or exceeds 50% of the market value or floor area of the existing structure or work.

4) minor additions/alterations;
   - construction that is less than 50% of the market value or floor area of the existing structure or work.

The proposed development limits shall be applied to new development (categories 1 and 2 above).

It is recognized that there may be restrictions to applying the new development limits to development category (3) - (infilling, replacement, major additions) and development category (4) - (minor additions/alterations). It would be permissible to allow these to proceed subject to:

- the placement of fill, and accessory buildings including pools not be allowed beyond the defined crest of valley slope;

- it being demonstrated by a qualified engineer that the structure(s) shall be safe for its assumed life and that the development will not have any negative impacts on the adjacent valley slopes.

It is also recognized that there may be restrictions to applying limits to essential servicing associated with new development i.e. storm sewers, sanitary connections, water, etc. Therefore, servicing will be permitted within the erosion impact zone provided it is safe from erosion and does not cause or accelerate erosion. Where practical, the location of servicing should follow existing corridors or easements.

NOTE: The development limits establish the rear property line and thus, the municipalities would still require a primary building setback from this point.

The development limit is recommended to be in public ownership as an environmental buffer zone; *however, the local municipality and the affected landowners will decide the best method of establishing the ownership of this limit.*

In sites where significant flora and/or fauna communities and/or species habitats extend beyond the 10 metres distance or where the existing vegetation is important for slope stability, the development limit shall be increased in distance to include the entire community. Examples of significant communities and/or habitats are:

- The Metropolitan Toronto and Region Conservation Authority's Environmentally Significant Areas;

- Ministry of Natural Resources Class 1- 7 wetlands;

- Ministry of Natural Resources Areas of Natural and/or Scientific Interest;

- Municipal Environmentally Significant Areas.

(b) *Erosion - Protection and Improvement*

(i) *The Authority shall continue to carry out erosion control works under its existing Erosion Control Program. In addition, a program of remedial works and/or acquisition shall be undertaken on Level 3 streams in lieu of effective runoff control. This additional program will also apply to Level 2 streams where MDP have not been implemented.*

(ii) Runoff controls and protective works shall also provide benefits to fisheries and riparian and terrestrial habitats where feasible.

8.6 Implementation of Public Safety (Erosion Control) Policies

(a) Prevention - Immediate Actions

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agency: Local Municipality

Time Frame: Initiate in 1990

Expand MTRCA and municipal enforcement programs to ensure compliance with development control and fill regulations, both during and after construction.
Extend floodline mapping and fill lines (development limits) to the 130 ha limit.

Prepare a Development Limit Policy for implementation through the plan input and review process.

Inventory and monitor existing storm water management storage facilities to calibrate erosion models and to determine their effectiveness in controlling erosion.

(ii) **Lead Agencies:** The Metropolitan Toronto and Region Conservation Authority and Local/Regional Municipalities

Time Frame: Initiated in 1990

Delineate Master Drainage Plan areas on a 1:10000 map base and incorporate them into municipal planning documents.

Establish a funding mechanism for erosion protection works and acquisition on Level 2 and 3 watercourses in lieu of runoff control.

(iii) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: MNR
MOE

Time Frame: Initiate in 1990

Prepare generic terms of reference for Master Drainage Plan Studies to ensure consistency with the Rouge River Drainage Study methodology and results including the preparation of guidelines for:

- Flood Control
- Erosion Control
- Water Quality
- Riparian Habitat
- Terrestrial Habitat

- o Fisheries
- o Aesthetics
- o Natural Channel design

(b) *Protection and Improvement - Immediate Actions*

(i) ***Lead Agency:*** *The Metropolitan Toronto and Region Conservation Authority and Local/Regional Municipalities*

Time Frame: *Initiate in 1990*

Carry out additional erosion protection works and acquisition on Level 2 and 3 watercourses in lieu of runoff control.

(ii) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agency: Local Municipality

Time Frame: Initiate in 1990

Amend the operational criteria contained within the Erosion and Sediment Control Program of the Watershed Plan to read all Level 1, 2 and 3 streams that drain in excess of 130 hectares.

TABLE 6

PUBLIC SAFETY
EROSION CONTROL

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- eliminate or minimize the threat to life and property from flooding and erosion within the Rouge River Watershed	- prevent the creation of new erosion prone development and minimize negative impacts associated with new developments	Lead Agency - MTRCA Participatory Agency - Local Mun. - expand enforcement programs to ensure compliance with development control and fill regulation - extend floodline mapping and fill lines to 130 ha limit - inventory and monitor existing SWM storage facilities to calibrate erosion models and determine effectiveness in controlling erosion	Initiate in 1990
		Lead Agency - MTRCA Participatory Agencies - MNR, MOE - prepare generic terms of reference for MDP studies including resource guidelines	Initiate within 1 year
		Lead Agencies - MTRCA, Local Mun. - delineate MDP areas on a 1:10,000 map base	Initiate within 1 year
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- protect existing development, land and terrestrial resources through remedial works and acquisition program	Lead Agencies - MTRCA, Local Mun. - carry out additional erosion protection works and acquisition on Level 2 and 3 watercourses in lieu of runoff control	Initiate within 1 year

FISHERIES

9.0 FISHERIES

9.1 Comment

The Rouge river supports fish populations which are recognized as having substantial present and future biological and recreational value.

The Rouge watershed can be broken into four physiographic zones that largely dictate the types of aquatic habitats and fish communities (typified by an indicator species) present:

- HEADWATERS: high gradient first and second order streams - brook trout.
- MIDREACHES: low gradient second and third order streams - smallmouth bass, rainbow trout (Little Rouge).
- LOWER REACHES: moderate gradient third and fourth order streams - rainbow trout (migratory).
- DELTA MARSH: low gradient fifth order stream flowing through extensive marsh on shore of Lake Ontario - northern pike, largemouth bass.

Aquatic habitats and fish communities were further refined and classified into stream levels (consistent with the flood and erosion impact zones). An indicator species was identified with each aquatic community to serve as the "barometer" of ecosystem health for that stream level of the Rouge watershed as follows:

Stream Level	*Indicator Species*
1	*downstream fish community*
2a	*Brook Trout*

2b	*Bass*
3a	*Bass*
3b	*Rainbow Trout*
4	*Bass, Pike*

However, protection, rehabilitation, enhancement or habitat creation efforts within the watershed should focus on ecosystem-based principles, not fish production principles, for example:

- *sustainable development, not sustainable yield*
- *management for healthy ecosystems, not for recreational fisheries*
- *presence of self sustaining populations of indicator species, not maximize the productive capacity of the river to produce sports fish*
- *rehabilitate/create the important habitat characteristics of a river system, not create/expand the most productive habitats for sports fish.*

The Comprehensive Basin Management Strategy, in adopting an ecosystem approach, recognises that migration of aquatic organisms, particularly fish, throughout the river is key to the establishment of the Rouge as a healthy ecosystem. Obstructions to fish passage are not acceptable unless equipped to allow upstream/downstream movement of fish.

By categorizing the watershed into stream levels with representative indicator species, there are transition zones (represented on Figure 5 by lines) between each stream level. In any river ecosystem there is no clear boundary between a coldwater and warmwater aquatic community; rather there is a gradual shift in the physical and chemical habitat attributes of the river that result in a change in the relative abundance in the warmwater and coldwater representatives of the river's aquatic community.

Often there are species whose habitat needs are better suited to these transition zones than either the coldwater or warmwater indicators. Brown and rainbow trout are prime examples of species which are suited to "cool" water habitats.

In dealing with land uses in these transition areas, the philosophy would be to focus on the indicator species whose habitat requirements are most sensitive. In general, this would afford adequate protection to the "transition" species. For example, protecting habitats for brook trout would also provide protection for brown and rainbow trout.

As outlined in Section 7 - Public Safety, Level 1 and 2 watercourses draining less than 130 ha are considered as a special subset of the stream classification system. From an aquatic ecosystem standpoint, these watercourses will be treated as a Level 1 stream unless they have the following characteristics:

- *well defined valley*
- *permanent flow/fish habitat*
- *natural terrestrial (woody) vegetation*
- *associated with a wetland, ANSI or ESA.*

In the latter case it will be treated as a Level 2 watercourse.

9.2 Specific Vision Statement

- Enjoy the beauty of natural aquatic habitats and riverbeds that are uncontaminated by abnormal algal growth and unsoiled by industrial and domestic wastes.

- Angle in the Rouge River with some expectations of encountering various preferred species of fish.

9.3 Technical Standard

(a) Meet Provincial Water Quality Objectives (Appendix 6).

(b) Use Habitat Suitability Index and indicator species to meet physical habitat conditions (Table 7 and Appendix 7).

9.4 Recommended Policies for Fisheries

9.4.1 Prevention

(a) The existing groundwater quantity should be maintained for baseflow in the Rouge River.

(b) The existing groundwater quality should be maintained.

(c) The aquatic habitats of the Rouge River shall be managed for designated indicator species *and to permit migration throughout the river.*

(d) A publicly owned riparian habitat zone (as described in Section 10.0) shall be established adjacent to:

i) all Level 2, 3 and 4 watercourses in excess of 130 ha;

ii) Level 1 and 2 watercourses less than 130 ha in drainage area if they have any of the following characteristics:

- ○ *well defined valley*
- ○ *permanent flow/fish habitat*
- ○ *natural terrestrial (woody) vegetation*
- ○ *associated with a wetland, or important terrestrial feature (eg. ANSI, ESA).*

TABLE 7

HSI STANDARDS

DESCRIPTION	RAINBOW TROUT	SMALL MOUTH BASS	BROOK TROUT
TEMPERATURE			
Mid summer noon maximum	24°C	30°C	
Minimum during growing season		18°C	11 - 16°C
Spawning season	10°C	11 - 26°C	4.5 - 10°C
Fry optimum			12.4 - 15.4°C
DISSOLVED OXYGEN			
MINIMUM	5 mg/1	4 mg/1	optimum > 7 mg/1 at < 15°C
Minimum for egg incubation	8 mg/1		optimum > 9 mg/1 at > 15°C
TDS			
Range for optimal growth		150 - 400 mg/1	< 20 ppm
TURBIDITY			
Maximum monthly average		< 50 JTU	optimum 0 - 3 JTU
Event maximum		250 JTU	
STREAM SHADING			
% shade (between 1000 - 1400 hrs.)		40 - 75%	

(e) The levels of ammonia, trace metals, pesticides and other organic compounds in water and aquatic sediments should be non toxic to fish and shall not bioaccumulate to levels in fish that are toxic to fish eating organisms.

(f) The occurrence and discharge to drainage systems of all spills shall be minimized.

9.4.2 Protection and Improvement

(a) The aquatic habitats of the Rouge River shall be managed for designated indicator species and to permit migration throughout the river.

(b) A publicly owned riparian habitat zone (as described in Section 10.0) shall be established adjacent to:

i) all Level 2, 3 and 4 watercourses in excess of 130 ha;

ii) Level 1 and 2 watercourses less than 130 ha in drainage area if they have any of the following characteristics:

- *o well defined valley*
- *o permanent flow/fish habitat*
- *o natural terrestrial (woody) vegetation*
- *o associated with a wetland, or important terrestrial feature (eg. ANSI, ESA).*

(c) The incidence of fish diseases, parasites and viruses in resident fish populations should be controlled to levels acceptable to the fishery.

(d) The occurrence and discharge to drainage systems of all spills shall be minimized.

9.5 Operational Criteria for Fisheries

9.5.1 Prevention

(a) The stream levels shall be managed for the aquatic communities represented by following indicator species (Figure 5):

Stream Level	Indicator Species
1	Downstream Fish Community
2a	Brook Trout
2b	Bass
3a	Bass
3b	Rainbow Trout
4	Bass, Pike

Master Drainage Plans and/or stormwater management plans must ensure that habitat needs of these species are met.

(b) Level 1 watercourses (intermittent streams) are important for downstream water quality and quantity and generally not for fish habitat within the Level 1 watercourse. Master Drainage Plans and/or stormwater management plans must ensure that the water quality and quantity is maintained and supportive of downstream fish communities.

For those Level 1 and 2 watercourses less than 130 ha with important fish habitat, riparian and/or terrestrial habitat, the Master Drainage Plan and/or stormwater management plan shall ensure these habitats are maintained.

(c) Overland soil erosion and sediment transport shall be controlled at sources such as construction sites, industrial and agricultural lands, and residential areas. Techniques could include:

- sediment traps, basins and ponds;

- conservation farming practices; and
- infiltration trenches and galleys.

For urban construction sites, additional guidelines are found within "Erosion and Sediment Control Guidelines for Urban Construction Sites".

(d) The Riparian Habitat Zone shall be managed to provide aquatic habitat benefits such as temperature regulation, cover and provision of food sources and organic matter. This zone shall be placed in public ownership.

9.5.2 Protection and Improvement

(a) The stream levels shall be managed for the aquatic communities represented by the following indicator species (Figure 5):

Stream Level	Indicator Species
1	Downstream Fish Community
2a	Brook Trout
2b	Bass
3a	Bass
3b	Rainbow trout
4	Bass, Pike

(b) Fish habitat improvement plans/projects could include the following techniques:

- streamside fencing and plantings;
- installation of log crib structure;
- installation of in-stream cover (log, boulder); and
- creation of spawning beds.

(c) The Riparian Habitat Zone shall be managed to provide aquatic habitat benefits such as temperature regulation, cover and provision of food sources and organic matter. This zone shall be placed in public ownership.

NOTE: Figure 6 shows the relationship of the various setback constraints outlined in the CBMS: top of bank, regional floodline, riparian habitat zone and erosion development setback. Adjacent to all of these are setback requirements of municipalities, for example, municipalities usually require a building setback of 7 - 10 m on private lands abutting open spaces. Thus, as a minimum in urban areas, a watercourse with fish habitat would have a 10 m riparian habitat zone in public ownership plus an additional 7 - 10 m municipal building setback in private ownership.

9.6 Implementation of Fisheries Policies

(a) Prevention - Immediate Actions

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agency: Local/Regional Municipality
MNR
MOE

Time Frame: Initiate within 1 year

Require all Master Drainage Plans for urbanizing areas to address implementation of control measures which will:

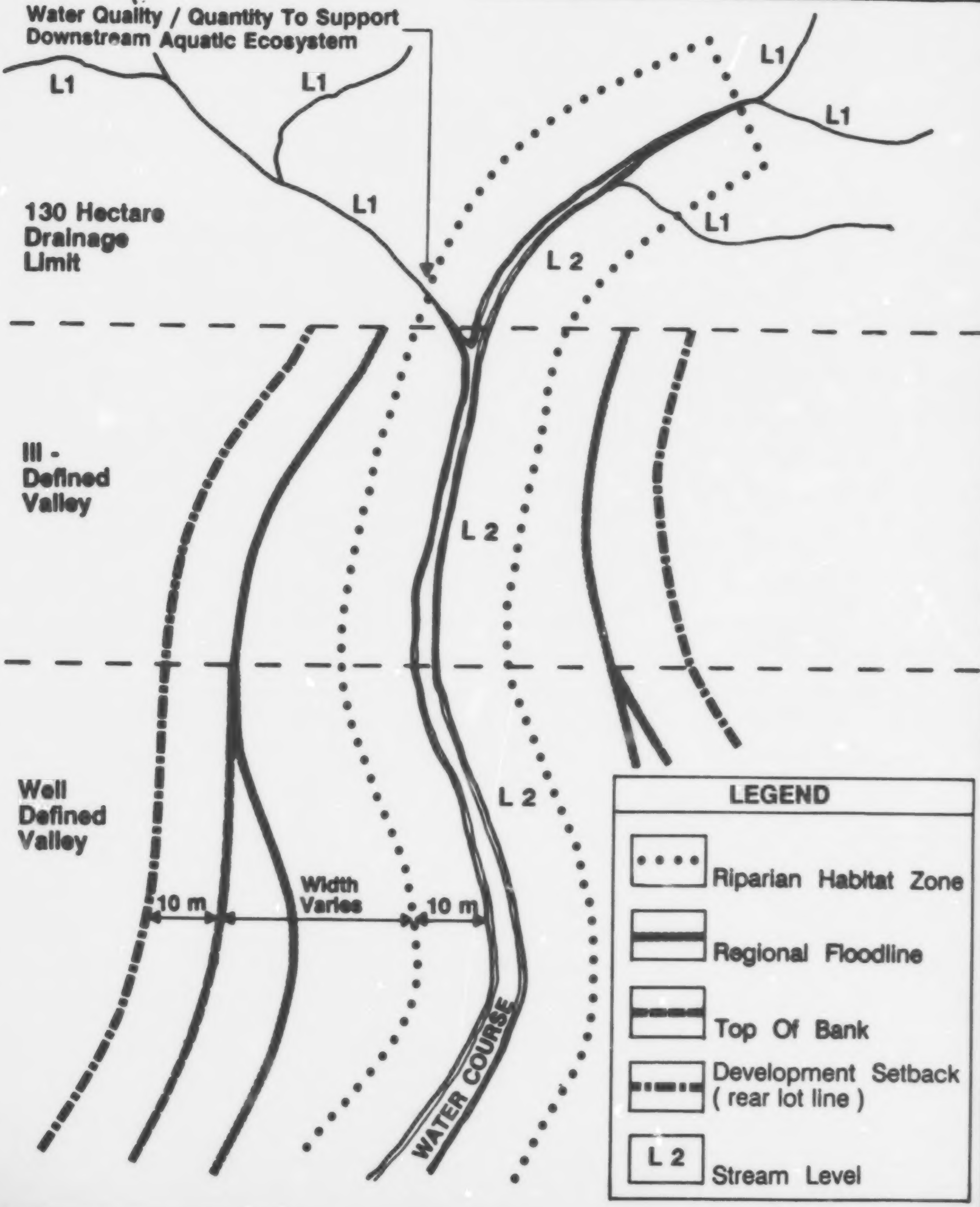
- provide control of overland soil erosion and transport during runoff;
- minimize the period of time that objectives for ammonia, metals and organic compounds are exceeded in runoff;
- incorporate methods of preventing spills from reaching watercourses;
- regulate the water temperature in the watercourses.

ROUGE RIVER BASIN
MANAGEMENT STRATEGY

RELATIONSHIP OF SETBACK CONSTRAINTS

JANUARY 1990

FIG. 6


Water Quality / Quantity To Support
Downstream Aquatic Ecosystem
L1
L1
L1
L1
L1
L1
130 Hectare
Drainage
Limit
L 2
Ill -
Defined
Valley
L 2
L 2
Well
Defined
Valley
10 m
Width
Varies
10 m
WATER COURSE
LEGEND
• • • • Riparian Habitat Zone
Regional Floodline
Top Of Bank
Development Setback
(rear lot line)
L 2 Stream Level

(ii) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: MNR

Time Frame: Initiate within 1 year

Define Habitat Suitability Index (HSI) criteria for target species in each community zone to more clearly express physical habitat needs in engineering design and planning terms.

(iii) **Lead Agency:** The Ministry of Natural Resources

Participating and Supporting Agencies: MTRCA
Local/Regional Municipalities
Non-governmental Organizations

Time Frame: Initiate within 1 year

Prepare a fisheries management plan for the Rouge River which will:

- o Develop generic terms of reference to assess fish habitat management needs on a sub-catchment basis for fish community zones for use in land use planning and master drainage planning studies.
- o Establish the current status of fish habitats and communities within each fisheries stream level through an extensive inventory program measuring appropriate HSI criteria and index of biotic integrity (IBI) metrics.

- Establish the habitat management requirement on a sub-catchment basis for all watercourses.

- Investigate the accessibility of existing and potential public access locations.

- Develop an information and education program to promote fishing opportunities.

(iv) *__Lead Agency:__* *The Metropolitan Toronto and Region Conservation Authority*

__Participating and Supporting Agencies:__ *MNR*
MOE
OMAF
Municipalities

__Time Frame:__ *Initiate in 1990*

Review policies regarding permitted uses in the floodplain to minimize impacts on the Riparian Habitat Zone.

(b) Prevention - Future Action

(i) **Lead Agency:** The Ministry of the Environment

Participating and Supporting Agencies: MNR
MTRCA

Time Frame: Initiate in 1990

Monitor contaminant levels in fish tissue from young-of-the-year Rouge River fish and in aquatic sediments as early indicators of the presence of potentially bioaccumulative chemicals and location of potential sources.

(c) Protection and Improvement - Immediate Actions

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies:

MNR
Local Municipalities
Non-governmental Organizations

Time Frame: Initiate within 1 year

Establish the Riparian Habitat Management Program that would prepare or undertake the following:

- Guidelines for riparian habitat management;

- Streambank plantings (priority may be given to salmonid watercourses) that meet riparian habitat technical guidelines;

- Streambank stabilization;

- Promote public education and encourage public interest groups to "Adopt-A-Stream".

The cooperation of the following existing programs or funding for these programs would be required:

- Ministry of Natural Resources Angling License Funds (those funds identified for stream rehabilitation);

- Community Fisheries Involvement Program;

- Metropolitan Toronto and Region Conservation Authority's Sediment Control Program;

- Environment Partners Fund;

- Municipal Valley Management and Naturalization Programs.

This Riparian Habitat Management Program could be expanded to include instream fisheries rehabilitation and environmental buffer management (tableland).

(ii) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Time Frame: Initiate in 1990 and thereafter, ongoing

Use opportunities provided by remedial works for flood and erosion control to rehabilitate physical habitats for target fish communities where feasible.

(iii) **Lead Agency:** Ministry of Natural Resources

Participating and Supporting Agencies: MTRCA
MOE

Time Frame: Initiate within 1 year

Monitor the incidence of disease, parasites and viruses in resident fish.

(iv) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: Local Municipality
OMAF

Time Frame: Initiate in 1990

Establish a public education awareness program to outline to landowners the benefits of implementing proper measures for controlling overland soil erosion and transport.

TABLE 8

FISHERIES

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- enjoy the beauty of natural aquatic habitats and river beds that are uncontaminated by abnormal algal growth and unsoiled by industrial and domestic wastes	- manage aquatic habitats for designated indicator species and to permit migration throughout the river - minimize occurrence and discharge of spills to drainage systems	Lead Agency - MNR Participatory Agencies - MTRCA, Local/Reg. Mun., Non-governmental Organizations - prepare a fisheries management plan for the Rouge River	Initiate within 1 year
- angle in the Rouge River with some expectations of encountering various preferred species of fish	- maintain existing groundwater quantity - maintain existing groundwater quality	Lead Agency - MTRCA Participatory Agency - MNR - define HSI criteria for target species in each community zone	Initiate within 1 year
	- establish a riparian habitat zone adjacent to watercourses	Lead Agency - MOE Participatory Agencies - MNR, MTRCA - monitor contaminant levels in fish tissue from young-of-the-year Rouge River fish and aquatic sediments as early indicators	Initiate in 1990
		Lead Agency - MTRCA Participatory Agencies - MNR, MOE, OMAF, Local Mun. - review policies regarding permitted uses in the floodplain to minimize impacts on the Riparian Habitat Zone	Initiate in 1990
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- manage aquatic habitats for designated target species and to permit migration throughout the river - minimize occurrence and discharge of spills to drainage systems	Lead Agency - MTRCA Participatory Agencies - MNR, Local Mun., Non-governmental Organizations - establish the Riparian Habitat Management Program	Initiate within 1 year
	- control disease, parasites and viruses in resident fish to acceptable fishery levels - establish a riparian habitat zone adjacent to watercourses	Lead Agency - MNR Participatory Agencies - MTRCA, MOE - monitor incidence of disease, parasites and viruses in resident fish	Initiate within 1 year

RIPARIAN HABITAT

10.0 RIPARIAN HABITAT

10.1 Comment

The Rouge River Urban Drainage Study did not have a specific component reviewing riparian habitats. However, conclusions from the water quality and fisheries components of the study indicated the importance of this habitat in protecting and improving the watercourse. Therefore, riparian habitat was incorporated as a main heading topic within the strategy.

10.2 Specific Vision Statement

- Enjoy with pleasure a healthy riverine/valley environment, watching birds, mammals and fish in their natural environment.

10.3 Technical Standard

Riparian habitat shall consist of indigenous plant species, be comprised of at least 50% woody species, and be a minimum of 10 m or twice the low flow channel width on each side of the watercourse, whichever is greater.

10.4 Recommended Policies for Riparian Habitat

10.4.1 Prevention

(a) A publicly owned riparian habitat zone shall be established adjacent to:

- *(i) all Level 2, 3 and 4 watercourses in excess of 130 ha;*
- *(ii) Level 1 and 2 watercourses less than 130 ha in drainage area if they have any of the following characteristics:*

- *well defined valley*
- *permanent flow/fish habitat*
- *natural terrestrial (woody) vegetation*
- *associated with a wetland, or important terrestrial feature (eg. ANSI, ESA).*

(b) Existing riparian habitat shall be protected and where possible, re-established.

10.4.2 Protection and Improvement

(a) A publicly owned riparian habitat zone shall be established adjacent to:

(i) all Level 2, 3 and 4 watercourses in excess of 130 ha;

(ii) Level 1 and 2 watercourses less than 130 ha in drainage area if they have any of the following characteristics:

- *well defined valley*
- *permanent flow/fish habitat*
- *natural terrestrial (woody) vegetation*
- *associated with a wetland, or important terrestrial feature (eg. ANSI, ESA).*

(b) Existing riparian habitat shall be protected.

10.5 Operational Criteria for Riparian Habitat

Currently this strategy has not developed operational criteria for riparian habitat. However, riparian habitats should be designed to include the following:

- provide food, cover and organic matter for aquatic organisms;

- regulate stream temperature;
- stabilize stream banks;
- control overland flows and sediment transport; and
- provide food, cover, shelter, nesting sites, migration corridors for terrestrial organisms.

NOTE: Figure 6 shows the relationship of the various setback constraints outlined in the Comprehensive Basin Management Strategy: top of bank, regional floodline, riparian habitat zone and erosion development setback. Adjacent to all of these are the setback requirements of municipalities, for example, municipalities require a building setback of 7 - 10 m on private lands abutting open space. Thus, as a minimum in urban areas, a watercourse with fish habitat would have a 10 m riparian habitat zone in public ownership plus an additional 7 - 10 m municipal building setback in private ownership.

10.6 Implementation of Riparian Habitat Policies

(a) Protection and Improvement - Immediate Action

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: MNR
Local Municipalities
Non-governmental Organizations

Time Frame: Initiate within 1 year

Establish the Riparian Management Program that would prepare or undertake the following:

- Guidelines for riparian habitat management;
- Streambank plantings (priority may be given to salmonid watercourses) that meet riparian technical guidelines;
- Streambank stabilization;
- Promote public education and encourage public interest groups to "Adopt-A-Stream".

The cooperation of the following existing programs or funding for these programs would be required;

- Ministry of Natural Resources Angling License Funds (those funds identified for stream rehabilitation);
- Community Fisheries Involvement Program;
- Metropolitan Toronto and Region Conservation Authority's Sediment Control Program;
- Municipal Valley Management and Naturalization Programs.

This riparian habitat management program could be expanded to include instream fisheries rehabilitation and environmental buffer management (tableland).

ii) ***Lead Agency:*** *The Metropolitan Toronto and Region Conservation Authority*

Participating and Supporting Agencies: *Municipalities*

__Time Frame:__ Initiate within 1 year.

Review MTRCA's land acquisition program for hazard lands and identify the extent to which the riparian habitat zone is included. Develop an acquisition program for any riparian habitats not previously identified.

(b) Protection and Improvement - Future Action

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: MNR
Local Municipality

Time Frame: Initiate within 1 year

Establish a public education and awareness program to outline the importance of healthy riparian habitats in providing passive recreation, maintaining important (functional) wildlife communities and minimizing overland soil erosion and transport to watercourses.

TABLE 9

RIPARIAN HABITAT

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- enjoy with pleasure a healthy riverine/valley environment, watching birds, mammals and fish in their natural environment	- establish a riparian habitat zone adjacent to watercourses	- no comment	- no comment
- angle in the Rouge River with some expectations of encountering various preferred species of fish	- existing riparian habitat shall be protected and where possible re-established		
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- establish a riparian habitat zone adjacent to watercourses	Lead Agency - MTRCA Participatory Agencies - MNR, Local Mun., Non-governmental Organizations - establish the Riparian Habitat Management Program	Initiate within 1 year
	- existing riparian habitat shall be protected	Lead Agency - MTRCA Participatory Agencies - MNR, Local Mun. - establish a public education and awareness program	Initiate within 1 year
		Lead Agency - MTRCA Participatory Agency - Local Mun. - review MTRCA's hazard land acquisition program for inclusion of the riparian habitat zone	Initiate within 1 year

TERRESTRIAL HABITAT

11.0 TERRESTRIAL HABITAT

11.1 Comment

Within the Rouge River watershed, a number of important and relatively large terrestrial habitats exist within the valleys. These have been identified and studied by numerous agencies and groups, and include:

- Environmentally Significant Areas (MTRCA);
- Carolinian Canada Sites (Carolinian Canada);
- Areas of Natural and/or Scientific Interest (MNR);
- Class 1 - 7 Wetlands (MNR).

The Rouge River Urban Drainage Study reviewed all available data on the terrestrial resources in the Rouge River valleys and also developed a framework to determine any impacts from hydrologic related changes.

The conclusions of the study indicated that predictable hydrologic changes would likely have little impact on terrestrial habitat cover other than those habitats immediately adjacent to the watercourse. In these situations, the habitat could be affected by increased flows and associated bank erosion, or increased water levels; but generally this would not be a major impact.

To assist in determining impacts on terrestrial habitats from hydrologic changes, a monitoring program of important habitats throughout the watershed could be undertaken.

11.2 Specific Vision Statement

- Enjoy terrestrial habitats that support sustaining populations of wildlife and waterfowl.

11.3 Technical Standard

The following is a list of known important terrestrial habitats:

- The Metropolitan Toronto and Region Conservation Authority's Environmentally Significant Areas (ESA);
- Carolinian Canada sites;
- Ministry of Natural Resources:
  - Evaluated Wetlands (Class 1-7)
  - Areas of Natural and/or Scientific Interest (ANSI);
- Municipal ESA.

11.4 Recommended Policies for Terrestrial Habitats

11.4.1 Prevention

Important flora and fauna areas such as MNR's evaluated wetlands, MTRCA's Environmentally Significant Areas (ESA), Carolinian Canada sites and Areas of Natural and Scientific Interest (ANSI - MNR) shall be protected (Figure 6).

11.4.2 Protection and Improvement

The following policy is the same as stated in the prevention component of the Terrestrial Habitat section; other than the policy includes a management element.

Important flora and fauna areas such as MNR's evaluated wetlands, MTRCA's Environmentally Significant Areas (ESA), Carolinian Canada sites and Areas of Natural Scientific Interest (ANSI - MNR) shall be protected and managed (Figure 6).

11.5 Operational Criteria

11.5.1 Prevention

(i) The Ministry of Natural Resources' Wetland Policy should be followed to provide protection to wetlands.

(ii) The Carolinian Canada's Stewardship Program provides guidelines to undertake protection programs of landowner agreements and conservation easements.

11.5.2 Protection and Improvement

(i) Guidelines for protection and management of important terrestrial habitats can be found in:

- Community Wildlife Involvement Program manual;
- Environmentally Significant Area Study (MTRCA, 1982); and
- ESA Management Guidelines (Draft - MTRCA).

11.6 Implementation of Terrestrial Habitat Policies

(a) Prevention - Immediate Action

(i) **Lead Agency:** Local/Regional Municipality

Participating and Supporting Agencies: MTRCA
MNR
Carolinian Canada

Time Frame: Initiate within 1 year

Accelerate existing programs of designating important floral and faunal features as environmental protection areas through the municipal planning process.

(ii) **Lead Agency:** The Ministry of Natural Resources

Participating and Supporting Agency:	MTRCA Carolinian Canada Non-governmental Organizations

Time Frame: Initiate within 1 year

Establish a resource monitoring program on selected significant terrestrial habitats to determine impacts from hydrologic changes.

(b) Protection and Improvement - Immediate Actions

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies:	MNR Carolinian Canada Non-governmental Organizations

Time Frame: Initiate in 1990

Establish a public education and awareness program to outline the importance of healthy terrestrial habitats in providing passive recreation, maintaining important (functional) wildlife communities and enhancing groundwater quantity and quality.

(c) Protection and Improvement - Future Action

(i) **Lead Agency:** The Metropolitan Toronto and Region Conservation Authority

Participating and Supporting Agencies: MNR
Non-governmental Organizations

Time Frame: Initiate in 1990

Establish a private lands stewardship program to rehabilitate terrestrial habitats on rural and urbanizing lands.

TABLE 10

TERRESTRIAL HABITAT

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- enjoy terrestrial habitats that support sustaining populations of wildlife and waterfowl	- Important flora and fauna areas, such as MNR's evaluated wetlands, MNR's ANSI, MTRCA's ESA, Municipal ESA, and Carolinian Canada sites shall be protected	Lead Agencies - Local/Reg. Mun. Participatory Agencies - MTRCA, MNR, Carolinian Canada - accelerate existing programs of designating important floral and faunal features as environmental protection areas	Initiate within 1 year
		Lead Agency - MNR Participatory Agencies - MTRCA, Carolinian Canada, Non-governmental Organizations - establish a resource monitoring program on selected significant terrestrial habitats to determine impacts from hydrologic changes	Initiate within 1 year
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- Important flora and fauna areas, such as MNR's evaluated wetlands, MNR ANSI, MTRCA's ESA, Municipal ESA, and Carolinian Canada, shall be protected and managed	Lead Agency - MTRCA Participatory Agencies - MNR, Carolinian Canada - expand land acquisition programs to place lands containing important floral and faunal features into public ownership	Initiate in 1990
		Lead Agency - MTRCA Participatory Agencies - MNR, Carolinian Canada, Non-governmental Organizations - establish public education and awareness program	Initiate in 1990

AESTHETICS

12.0 AESTHETICS

12.1 Comment

The Rouge River Urban Drainage Study reviewed on the aesthetics in the watercourse only with respect to those parameters that would also impact the water quality, The water quality component of the study indicated that turbidity and site specific locations for aquatic growth were of concern, however, were not a major impact. Nevertheless, to provide a complete and comprehensive management strategy, an aesthetic component was included. Many of the policies, operational criteria and implementation within the other sections of the strategy will assist in meeting aesthetics objectives.

12.2 Specific Vision Statement

o Delight in the enjoyment of clear stream waters (in the seasons when waters should normally be clear) that have no unpleasant odour, abnormal algal growth, or industrial and domestic wastes.

12.3 Technical Standard

(i) The water should be sufficiently clear that a Secchi disc is visible at a minimum of 1.2 m.

(ii) The turbidity of water should not be increased more than 5.0 NTU (nephelometric turbidity units) over natural turbidity when this is low (<50 NTU).

(iii) Oil or petrochemicals should not be present in concentrations that:

- can be detected as a visible film, sheen or discoloration on the surface;
- can be detected by odour; or

- can form deposits on shorelines and bottom deposits that are detectable by sight and odour.

(iv) All waters should be free from:

- materials that will settle to form objectionable deposits;
- floating debris, oil, scum and other matter;
- substances producing objectionable colour, odour, taste or turbidity; and
- substances and conditions or combinations thereof in concentrations which produce undesirable aquatic life.

(v) Phosphorus levels should not exceed concentrations of 0.03 mg/l for dry periods and the exceedance of existing guidelines be minimized for wet periods.

12.4 Recommended Policies for Aesthetics

12.4.1 Protection and Improvement

(i) The Ministry of the Environment's PWQG for phosphorus shall be met during periods of no runoff.

(ii) The frequency and length of time that phosphorus objectives are exceeded during periods of runoff shall be minimized.

(iii) The guidelines for clarity, turbidity, aesthetics and oil and grease (Canadian Water Quality Guidelines, 1987) should be met.

12.5 Operational Criteria

No operational criteria are provided at this time.

12.6 Implementation of Aesthetics

Protection and Improvement - Immediate Actions

(i) **Lead Agency:** Local Municipality

Time Frame: Initiate in 1990

Eliminate and/or control dry weather phosphorus sources such as illegal waste discharges to storm sewers, faulty septic systems.

(ii) **Lead Agency:** Local/Regional Municipalities

Time Frame: Continue in 1990 and thereafter, ongoing

Maintain and/or extend municipal spill action control programs. (see 6.6 (c)(iii)).

TABLE 11

AESTHETICS

VISION	PRINCIPAL POLICIES	IMPLEMENTATION	TIME FRAME
	PREVENTION	PREVENTION	
- delight in the enjoyment of clear stream waters (in seasons when waters should normally be clear) that have no unpleasant odour, abnormal algal growth, or industrial and domestic wastes	- no comment	- no comment	- no comment
	PROTECTION AND IMPROVEMENT	PROTECTION AND IMPROVEMENT	
	- MOE's PWQO for phosphorus shall be met during periods of no runoff	Lead Agency - Local Mun. - eliminate and/or control dry weather phosphorus sources	Initiate in 1990
	- minimize the frequency and length of time that phosphorus objectives are exceeded during periods of runoff - guidelines for clarity, turbidity, aesthetics and oil and grease (CWQG 1987) should be met	Lead Agencies - Local/Reg. Mun. Participatory Agency - MOE - maintain/extend municipal spill action control programs	Continue in 1990 and thereafte ongoing

13.0 THE ROUGE RIVER BASIN MANAGEMENT STRATEGY: A LONG STEP FORWARD - BUT NOT THE FINAL STEP?

The preparation of the Rouge River Basin Management Strategy is a significant event in the evolution of the policies and programs of The Metropolitan Toronto and Region Conservation Authority.

Less than a decade ago, the Authority's approach to stormwater and urban drainage management and erosion control essentially consisted of carrying out individual, localized remedial works. A series of events in the 1980's (described in S.3.1) led the Authority to question both the adequacy and the cost-effectiveness of this piecemeal approach, and to recognize the need to address each watershed as a functional unit rather than as a collection of isolated water management problems.

This perception had two further important implications.

First, it led to recognition of the watershed as an ecosystem whose diverse components, natural and man-made, were all interrelated. This in turn meant that planning for water management in effect entailed planning for the ecosystem.

Second, watershed planning could not be made the sole responsibility of a single agency, even one with as broad a mandate as a conservation authority, because it inevitably involved matters that were the responsibility of other agencies. It had to become a cooperative endeavour with the full participation of the municipal governments and provincial ministries that held these responsibilities. Moreover, because of the interests of watershed residents and of other non-governmental groups in different aspects of watershed planning, provision for the participation of the public as well was essential.

The first concrete expression of this new thinking was the Rouge River Urban Drainage Study, initiated by the City of Scarborough and Save the Rouge Valley System in 1986.

For the first time MTRCA chose to examine a specific issue, the management of urban drainage, throughout an entire watershed, in relation to other water management issues, in an ecosystem context, in cooperation with other public agencies, and with the participation of citizen groups.

Another manifestation of the new thinking was the Authority's 1988 Strategy for Watershed Management, which not only set out these principles explicitly as the framework for future watershed planning, but recognized that each watershed in the Metro Toronto Region not only is itself an ecosystem but also falls into place as part of a larger ecosystem.

Perhaps even more significantly, the MTRCA's 'A Strategy for Watershed Management' also stressed the need to maintain a balance between economic and ecological health, carrying in somewhat different words the identical message brought to Canada the previous year by the Brundtland Report on Environment and Development and that of the National Task Force on Environment and Economy.

This is the sequence of events that led to the Rouge River Watershed Management Strategy. The plan is not a product of theory or ideology but the outcome of a process of learning from very practical experience, a process which led inexorably to the conclusion that planning for water management has to be both comprehensive and cooperative.

The outstanding question raised, in fact, by this learning process is: is even comprehensive water management planning enough? Expressed a little differently, is it appropriate or practical to separate planning for water management from land and environmental planning in general?

The intention here is clearly not to suggest that the MTRCA, or any other agency, should take over as a sort of supreme land and water planning authority for the Metro Region. It is not even intended to suggest that such a function should, or could, be exercised collectively by several different agencies.

However, the MTRCA's experience over the past decade, culminating in its 1988 Greenspace for the Greater Metro Region report and in the Rouge River Watershed Management Strategy, points very clearly to the need for a broad, cooperatively developed, land/water/environmental policy framework for the Region, within which each public agency could exercise its own responsibilities with regard to, for example, municipal land use planning, transportation planning, and environmental assessment. The need is emphasized by the Ontario government's appointment of an Environment-Economy Round Table with a mandate to develop a provincial sustainable development strategy, a strategy, in the words of the MTRCA's own 'A Strategy for Watershed Management', to "balance ecological health and quality with economic growth and development". A land/water/environment policy for The Metropolitan Toronto Region could make a vital contribution to a provincial sustainable development strategy, and would in turn be reinforced by the strategy.

The Rouge River Basin Management Strategy is a long step forward in environmental planning in the Metropolitan Toronto Region, but it should not be the last.

14.0 GLOSSARY

base flow: stream discharge from groundwater sources.

basin: in hydrology, the area drained by a river.

channel: a natural stream that conveys water; a ditch or channel excavated for the flow of water.

channelization/channel improvement: the improvement of the flow characteristics of a channel by clearing, excavation, realignment, lining or other means, in order to increase its capacity.

cold water fishery: a fresh water, mixed fish population, including some salmonids.

conservation: "wise use" or "multi purpose use" or "the greatest good for the greatest number for the longest possible time".

ecosystem: a natural unit of living and nonliving components which interact to form a stable system in which a cyclic interchange of materials takes place between living and nonliving units.

enhancement: in an extreme form is a culture in which the ecosystem is brought under close human control, as close as necessary to effect the relevant human purposes.

erosion: wearing away of land surface by running water, wind, ice or other geological agents. Detachment and movement of soil or rock fragments by water, wind, ice or gravity.

fauna: the animals living within a given area or environment during a stated period.

fill: any material deposited by an agent for as to fill or partly fill a channel, valley, or other depression.

flood: an overflow or inundation that comes from a river or body of water and causes or threatens damage.

flood event: an occurrence based upon the measurement or calculation of the volume of runoff or peak flow that results from any given rainfall or snow melt.

100 year flood: the flood that based on historical data, occurs on the average once in 100 years. It is based on peak flows as opposed to rainfall amounts.

flood peak: the highest value of the stage or discharge attained by a flood.

floodplain: nearly level land situated on either side of a channel which is subject to overflow flooding.

flora: the aggregate of plants growing in and usually peculiar to a particular region or period.

groundwater: subsurface (below ground) water in the zone of saturation.

headwater: the source of a stream; the water upstream from a structure or point on a stream.

hydrology: a science dealing with properties, distribution and circulation of water on the surface of land, in the soil and underlying rocks, and in the atmosphere.

impervious/impermeable soil: a soil through which water, air or roots cannot penetrate.

intermittent streams: a stream or portion of a stream that flows in direct response to precipitation and is dry for a large part of the year.

marsh: a periodically wet or continually flooded area where the surface is not deeply submerged; covered dominantly with sedges, cattails, rushes, or other hydrophytic plants.

moraine: an accumulation of glacial drift, generally of rock, gravels, and sands.

restoration: attempts to recover some of the features of the initial wild state currently perceived as particularly desirable.

stream order: A classification system that numbers the tributaries of a river beginning with headwater tributaries and increasing the order number as lower order tributaries join the mainstream.

sustainable development: the integration of environmental and economic factors in resource management decision-making.

warm water fishery: a fresh water, mixed fish population, with no salmonids.

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APPENDICES
OF
A COMPREHENSIVE BASIN MANAGEMENT STRATEGY FOR THE ROUGE RIVER WATERSHED

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APPENDICES

OF

A COMPREHENSIVE BASIN MANAGEMENT STRATEGY FOR THE ROUGE RIVER WATERSHED

APPENDIX 1

APPENDIX 1

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	Mr. Jonathan P'Ng	Water Resources Branch
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APPENDIX 1 (cont'd. ....)

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Conservation Council of Ontario	Mr. Glenn Harrington
Save the Rouge Valley System	Mrs. Lois James
Toronto Field Naturalists	Mrs. Helen Juhola
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Save the Rouge Valley System	Mr. Stephen Marshall
Save the Rouge Valley System	Ms. Patricia Paley
Save the Rouge Valley System	Mr. Jim Robb
Conservation Council of Ontario	Ms. Ellen Schwartzel
Save the Rouge Valley System	Ms. Donna Shaw
University of Guelph	Mr. Mike White

APPENDIX 2

APPENDIX 2

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*The technical Committee members also attended the Stakeholders meetings.

APPENDIX 3

APPENDIX 3

ROUGE RIVER URBAN DRAINAGE STUDY CONCLUSIONS

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1. INTRODUCTION

The Rouge River Urban Drainage Study was initiated in 1986 as a prototype watershed study aimed at assessing and mitigating the water basin impacts of future urban growth on flooding, erosion, water quality and environmental resources in the Rouge River and its tributaries.

The study used state of the art modelling and assessment techniques and employed experts from the field of hydrology, erosion processes, water quality and aquatic ecology to complete a series of technical studies describing existing basin characteristics, predicting future changes and examining the effectiveness of current and stormwater practices. The Phase I technical studies have been completed by Marshall, Macklin, Monaghan Ltd. and Beak Consultants Ltd. and consisted of seven (7) volumes:

- o Volume 1: Executive Summary
- o Volume 2: Subwatershed Hydrologic Modelling
- o Volume 3: Subwatershed Water Quality Modelling
- o Volume 4: Subwatershed Runoff Control Study
- o Volume 5: Subwatershed Erosion Control Study
- o Volume 6: Watershed Water Quality Assessment
- o Volume 7: Watershed Environmental Studies

Draft Phase II technical studies have been completed by Marshall, Macklin, Monaghan Ltd. and Beak Consultants Ltd. and consisted of five (5) volumes:

- o Volume 1: Completion of Subwatershed Studies (channelization and erosion control studies)

- o Volume 2: Watershed Wide Studies (hydrology, runoff control, channelization and erosion control studies)

- o Volume 3: Flood Control Study - Upper Rouge Study
- o Volume 4: Water Quality Study - Phase II
- o Volume 5: Environmental Studies Phase II

At the completion of the draft Phase II technical reports, the Metropolitan Toronto and Region Conservation Authority (MTRCA) assembled a Technical Committee comprised of recognized experts in a number of fields. In addition, a stakeholders committee comprising those municipalities, provincial agencies and public groups with a mandate and/or interest in the Rouge Watershed was formed. Both of these groups assisted the MTRCA in:

- o reviewing and qualifying the conclusions of the Rouge River Urban Drainage Study;
- o producing a Vision which described in human terms the essential natural features of the Rouge Watershed;
- o establishing a number of goals regarding the future use of the Rouge watershed; and
- o developing a watershed management strategy outlining immediate actions and future requirements.

The conclusions of the Rouge River Urban Drainage Study have been summarized in the following sections. These conclusions form the basis on which the Vision and recommended watershed policies were developed.

1.1 Flood Control

1.1.1 Introduction

It is the MTRCA's mandate as a watershed manager to minimize the threat to life and property as a result of flooding. To fulfil this mandate, the Authority has identified and inventoried numerous flood susceptible sites on the Rouge River, and has developed and implemented a flood control policy for its entire jurisdiction.

One of the objectives of the Rouge River Urban Drainage Study was to evaluate the MTRCA's current policy for runoff control as it relates to flood control on the Rouge River for both technical effectiveness and cost effectiveness.

1.1.2 Modelling Overview

(a) The objective of this study was to determine the sensitivity of the Rouge River watershed hydrology to increasing urbanization and to predict the nature of potential impacts.

(b) The QUALHYMO model was used to predict different types of flows in order to assess the sensitivity. These flows may be categorized as follows:

- i) unusual or rare flows (eg. 100 year flood, Regional flood);
- ii) frequent flows (eg. 2 year flood);
- iii) average or low flows.

c) The indicators of hydrologic impacts are:

- water levels
- flow velocity

- flow duration
- water quality

Flow data is used to interpret these indicators. The most significant indicator for flood control purposes is water level.

(d) The Regional flood and/or "rare" events are used as indicators for flood control purposes. This is generally accepted engineering practice and in conformity with the provincial Floodplain Planning Policy Statement and Guidelines.

(e) Changes in flow can result in changes in water levels. These changes may be measurable. The accuracy of the measured changes is limited by:

- tolerance limits of the model
- accuracy of the data
- accuracy of measurements
- accuracy of mapping

Given the above limitations:

i) a change in water level of 5 cm can be considered "insignificant";

ii) a change in water level of 6 cm - 15 cm can be considered "minor";

iii) a change in water level of 16 cm - 40 cm can be considered "cautionary", requiring further investigation;

iv) a change in water level exceeding 40 cm can be considered "significant" (this amount is in excess of accepted engineering practice for construction/design of incorporating a "freeboard" or "safety factor" above the design water level - usually of 35 cm).

(f) Large changes in flow can result in smaller or small changes in water level.

(g) In the case of an ill-defined, or relatively flat floodplain, a change in water level can result in a change in the floodplain limits (i.e., the topwidth of the floodplain). In the case of a well defined valley, changes in water level may result in only very small changes in topwidth.

1.1.3 Interpretation of Modelling Results

(a) General

i) The modelling approach was reasonable and followed generally accepted engineering practices.

The model is acceptable as a "planning level" study.

ii) The model confirmed that the Rouge River watershed is a complex drainage basin and that a computer modelling exercise was essential to evaluate hydrologic responses and the effects of land use changes on complex non-homogenous basins.

iii) Scientific research demonstrates that several models can show similar hydrologic trends (i.e., the results of this study were not model specific). The Rouge study results confirmed this.

iv) The model is sensitive to the following:
   (a) data;
   (b) calibration and verification;
   (c) changes in land use.

(b) Trends

i) The model demonstrated that a change in land use without runoff control can result in a change in flows. The extent of the change in flows is dependent upon:

- (a) type of land use change;
- (b) percentage of land use change;
- (c) distribution within the watershed of land use change.

ii) The Rouge River watershed may be considered in terms of four impact zones:

- (a) Level 1 (micro-system)
  These watercourses generally are pipes, swales and ditches, and are characterized by intermittent flows.
- (b) Level 2 (tributary system)
  These watercourses can be 1st, 2nd or 3rd order streams and are characterized by a defined low-flow channel and continuous flow.
- (c) Level 3 (river system)
  These watercourses are generally 4th and 5th order streams and up, generally drain in excess of 5,000 ha and are considered the principal watercourses in a watershed.
- (d) Level 4 (lacustrine marsh)
  This watercourse is part of a Lake Ontario waterfront marsh. Water levels are influenced by Lake Ontario.

iii) The model showed that the hydrologic impacts of changing land uses are different from different stream levels and different return period events. The impacts can be summarized as follows for the range of urbanization considered (Figure A-1):

(a) Level 1

In a rural condition, flows are negligible. Urbanization causes large percentage increases in flows; however, the magnitude of the flow is still small, and changes in water level can be considered insignificant since these watercourses typically are incorporated into the storm sewer system design.

The hydrologic impacts on Level 1 watercourses become significant only in terms of the potential cumulative impacts on downstream watercourses. This is true for both frequent and rare events.

(b) Level 2

This is the first level where the cumulative effects of land use changes are felt. The most significant increases in flows from changing land use are felt on Level 2 streams.

Under the high growth scenario, there is a "cautionary" and potentially "significant" increase in water levels on Level 2 tributaries immediately downstream of uncontrolled development for both 2 year and 100 year flows.

Under Regional flow conditions, there is a "minor" increase in water levels at some points and no increase at others.

(c) Level 3 and 4

At these stream levels changes in the ratio of flow increases is smaller. The cumulative effects of upstream land use changes are increasingly dampened out as drainage area increases.

Under the high growth scenario, there is a "minor" or "insignificant" increase in water levels on the main tributaries of the Rouge and Little Rouge Rivers for both 2 year and 100 year flows.

Under Regional low conditions, there is generally no increase in water levels. Only at one of the flow points examined was there a "minor" increase in water level.

1.1.4 Runoff Control Effectiveness

The effectiveness of runoff control can also be discussed in terms of stream levels (Figure A-2).

(a) Level 1

The study showed that runoff controls can effectively control all peak flows for Level 1 streams to pre-development levels.

(b) Level 2

The study showed that runoff control implemented on Level 1 streams does not ensure that control will be achieved on downstream Level 2 streams due to changes in the timing of flows.

For 2 year and 100 year flows, peak flows were mostly between 5% and 30% higher than existing flows.

The Rouge Study results showed that runoff control for Level 2 streams can be effective if it is designed on subwatershed basis.

(c) Level 3 and 4

The study showed that upstream runoff control is not effective in controlling 2 year and 100 year flows in Level 3 and 4 streams.

The generally accepted practice of designing upstream runoff control facilities to achieve a zero increase in downstream peak flows is not effective for Level 3 and 4 streams.

Other runoff control alternatives were examined, including over-control on some tributaries. Within the range of cost-effective solutions examined, the study showed that selective upstream over-control is not effective in controlling 2 year and 100 year peak flows on Level 3 and 4 streams.

The study results indicated that large on-line facilities may be required to effectively control downstream flows in Level 3 and 4 streams. In other words, for Level 3 and 4 streams, runoff control is achieved through centralized storage which can be equated with flood control. Dams for flood control may be reviewed and considered along with other remedial works options.

Flood control for Level 3 and 4 streams is not effective for controlling flows in Levels 1 and 2 streams. In other words, centralized facilities to control flows in Level 3 and 4 streams does not eliminate the need for upstream control.

1.1.5 Channelization

(a) The study demonstrated that extensive channelization utilizing a traditional trapezoidal design can increase peak flows for all storms due to reduced travel times in both Level 2 and Level 3 streams.

The increase in Regional flood levels for Level 3 streams under high growth scenario and full channelization is "cautionary" and potentially "significant".

Under the high growth scenario with partial channelization, increases in water levels are "insignificant".

(b) The study showed that extensive channelization utilizing a traditional trapezoidal design can reduce the effectiveness of runoff control facilities if reduced travel times are not incorporated into the design.

1.1.6 Recommended Strategy

(a) The study has demonstrated that a "blanket" policy of runoff control for flood control purposes is not effective on a watershed basis.

- i) Based on the study results, runoff control should no longer be implemented upstream of the Unionville Damage Centres solely for flood control purposes.
- ii) Instead, a program of remedial works and acquisition should be developed for the Unionville Damage Centres.

(b) In addition to the Unionville Damage Centres, there are 31 other known flood susceptible sites on Level 2 and 3 streams within the Rouge River watershed. These are shown on the attached Figure A-3.

- i) These sites should be prioritized in terms of potential flood damages.
- ii) Flood Susceptible Sites on Level 2 Streams
  Master Drainage Plans should be prepared for all Level 2 streams prior to any new development occurring, to assess the need and various options for runoff control.

One component of the Master Drainage Plan should be a detailed assessment of all existing flood susceptible sites and the potential impacts of development. Specific plans for works and/or acquisition should be developed that would include cost-benefit analyses and cost/cost-sharing.

iii) Flood Susceptible Sites on Level 3 Streams

The study showed that upstream runoff control is not effective in controlling flows in Level 3 streams. There is, therefore, no justification for requiring upstream runoff control to protect flood susceptible sites on Level 3 streams.

Instead, an acquisition plan should be developed for flood susceptible sites on Level 3 streams. This plan would include:

- priority for acquisition;
- estimated costs;
- mechanisms to levy upstream developers;
- implementation of strategy;
- funding administration.

As a watershed manager, the MTRCA is the logical agency to develop and implement this plan with the cooperation of its member municipalities.

In addition, a mechanism should be developed whereby the MTRCA may collect and administer funds for remedial works on Level 3 streams in lieu of upstream runoff control.

(c) Terms of reference should be prepared for master drainage plans within the Rouge River watershed to ensure consistency in approach and compatibility with the Rouge Study methodology and results.

(d) i) Traditional channel design should be discouraged because of the cumulative hydrologic impacts demonstrated by this study. Traditional channel design may be permitted in cases where there is a flood control benefit associated with it.

ii) Alternative channel designs should be investigated to determine if the hydrologic impacts of channelization can be mitigated. Based on this analysis, guidelines for channelization may be prepared.

iii) Channelization should be strongly discouraged where there is:

- a well defined valley;
- a terrestrial resource concern;
- a fishery resource concern.

Master drainage plan studies for Level 2 streams may uncover additional reaches where this criteria may apply.

Channel improvements may still be considered on a site-by-site basis.

iv) Channelization will only be considered in the context of a master drainage plan where the hydrologic impacts of channelization can be mitigated, and other planning, environmental or related concerns can be addressed.

(e) A hydrologic "model maintenance" program should be developed that includes:

- staff training;
- monitoring/data collection;
- model adjustment/refinement;
- model updating.

The MTRCA should be "custodian" of the Rouge River hydrology model.

1.2 EROSION CONTROL

1.2.1 Introduction

It is the Metropolitan Toronto and Region Conservation Authority's mandate as a watershed manager to minimize the hazard to life and property from channel or valley wall erosion. To fulfil this mandate, the Authority has identified and inventoried numerous erosion sites on the Rouge River and implemented both a protection program through remedial works, and a preventative program through the implementation of Authority regulations and through commenting as part of the plan input and review process including a Stormwater management Program.

The two main objectives of the erosion component of the Rouge River Urban Drainage Study was to assess the impact of urbanization of river erosion and to evaluate the effectiveness of the MTRCA's current Stormwater Management Program in preventing erosion.

1.2.2 Statement of Conclusions

The purpose of the erosion control component of the study was to "determine the effects of urbanization on stream and channel erosion and the effectiveness of stormwater management ponds to control erosion in downstream watercourses".

(a) General Overview

i) Erosion is a natural phenomenon.

ii) Urban hydrologic changes can aggravate or accelerate channel erosion, however, the rate of erosion varies dependent on; geomorphologic characteristics, soil types, % urbanized, distance from urbanization.

iii) Urbanization has less effect on the unusual or rare flows (eg. 100 year/Regional Floods) than on the frequent flows (eg. 2 year flood). It may not be practical from a technical and cost effectiveness perspective to control the unusual or rare flows for erosion control.

iv) A large number of erosion sites exist in the Lower Rouge (below Steeles Avenue). Currently, they are not significant in relation to hazard of public or private structures. The gradient and soils through this reach of the Rouge combine to create a high potential for erosion.

v) Under existing land use, there is a low potential for erosion in the remainder of the Rouge watershed.

vi) A theoretical method of controlling channel erosion is to attempt to obtain true zero increase in runoff rather than only a zero increase in peak flow. However, such an approach is much more difficult if not impossible to achieve.

vii) Based on the study results, runoff control practised on Level 1 and 2 streams, are not effective in controlling flows on Level 3 streams and, therefore, cannot be effective in controlling an increase in erosion potential.

(b) Modelling Overview

The purpose of the erosion model was to test the storage effectiveness vs. uncontrolled runoff as it relates to erosion.

The erosion modelling indicated the following:

i) Erosion is a site specific phenomenon and is a very complex problem dependent on various geomorphic characteristics, various flow characteristics and soils and therefore, a blanket stormwater management policy is not effective;

ii) Peak flow increases may or may not accelerate erosion;

iii) Duration and volume of flow runoff is as important as peak flow in increasing erosion potential and that existing stormwater management practices appear to be ineffective in reducing the erosion potential when runoff is controlled to predevelopment levels;

iv) Limitations of the model and the lack of historical data meant that the modelling could indicate erosion potential but was unable to predict the extent of the erosion or determine the most effective design of storage facilities for erosion control.

v) The model has provided direction for future research;

vi) The Authority's Stormwater Management Policy for erosion control was a step in the right direction, however, it may not always be effective in providing erosion control benefits.

1.2.3 Implications/Trends

(a) The study recognized a weakness in the technical ability of the erosion model to accurately predict the effects of flow changes on erosion. Therefore, the confidence level regarding the effectiveness of runoff control in minimizing erosion increases is low.

(b) Runoff control on Level 1 and 2 streams does not appear to be effective in controlling flows on Level 3 streams and, therefore, we must assume that it will not be effective in preventing erosion. If upstream preventative work is not effective, then the Authority should consider alternative solutions to deal with the potential problem.

(c) Regardless of urbanization, unusual or rare events will cause significant erosion damages throughout the watershed. It is not cost effective to provide erosion protection for these events.

1.2.4 Recommended Strategy

(a) The study has demonstrated that the current blanket stormwater management policy for erosion control may not be effective on a watershed basis and should be discontinued.

(b) Master Drainage Planning should include an erosion study which would identify Level 1 and 2 streams where detention facilities would be effective, and Level 1 and 2 streams where protective works should be implemented. A provision should be made to install protective works on Level 1 and 2 streams where detention facilities prove ineffective.

A policy of local control should be retained in an attempt to protect Level 1 and 2 streams of high quality from high erosion potential resulting from major increases in flow projected in some areas of development.

Protective works, on Level 1 and 2 streams not identified as high quality, should be implemented in lieu of stormwater management. An opportunity for enhancement/rehabilitation of Level 1 and 2 streams which are under stress is possible through this process.

(c) In addition to the Authority's existing remedial works program, a mechanism should be developed within the watershed whereby the MTRCA can collect and administer funds for preventative protective works on Level 3 streams in lieu of upstream runoff control. A monitoring program on Level 3 streams should be implemented to assess the impacts of increased flows and to determine when and where protective works should be carried out.

(d) Guidelines for design of the most efficient detention facility should be prepared based on existing technology and provision for updating the design should be made as the technology and calibration data improve.

(e) A monitoring program should be established to determine the effectiveness of storage facilities and a program for collecting the required calibration data for use in complex erosion models should be initiated and maintained.

(f) The Authority's practice of preventing development within erosion prone areas should be continued and a review carried out to determine if the existing setback guidelines are adequate.

(g) Design of all preventative remedial works should be cognizant of the flood control, fisheries and water quality objectives and their design criteria incorporated into erosion works where appropriate.

1.3 FISHERIES

1.3.1 Introduction

The Rouge River supports fish populations which are recognized as having substantial present and future biological and recreational value. A Rouge River watershed plan must address the aquatic habitat problems and needs related to the fish communities being protected and managed. This is particularly critical as the pace and nature of urbanization have a dramatic effect on future land uses which, in turn, have a direct effect on physical, chemical and biological conditions in the Rouge River.

With this broad objective in mind, the Rouge Study undertook the following:

(a) to document the current conditions of fish populations and their habitats throughout the watershed;

(b) to identify indicator or target fish species for each fish community type to facilitate habitat management;

(c) to apply Habitat Suitability Index (HSI) models for these target fish species to the Rouge River;

(d) using HSI models, assess the nature and degree of aquatic habitat change which could be expected with several urban development scenarios in the Rouge watershed; and

(e) to establish an analytical framework and set of habitat criteria for future protection, management and enhancement of fish communities in the Rouge River.

1.3.2 Summary of Rouge Study Conclusions

The following provides a general summary of the conclusions of the fisheries component of the Rouge Study.

(a) Existing Conditions

i) The Rouge watershed can be broken into four physiographic zones that largely dictate the types of aquatic habitats and fish communities present:

- HEADWATERS: high gradient first and second order streams originating on the Oak Ridges Moraine. Existing land uses are predominantly agriculture, and estate residential.
- MIDREACHES: low gradient second and third order streams flowing across a relatively flat clay plain. Existing land uses are predominantly agriculture and rapidly expanding urbanization.
- LOWER REACHES: moderate gradient third order streams flowing through deeply incised forested valleys. Existing land uses are predominantly Authority lands and urban development.
- DELTA MARSH: low gradient fourth order stream flowing through extensive cattail marsh on shore of Lake Ontario. Existing land uses are predominantly Authority lands and urban development.

ii) Each zone has a characteristic fish community or guild typified by an indicator species, as follows:

- HEADWATERS: brook trout (resident coldwater community)

- MIDREACHES: smallmouth bass (resident warmwater community); rainbow trout (Little Rouge)

- LOWER REACHES: rainbow trout (resident warmwater/migratory coldwater community)

- DELTA MARSH: northern pike, largemouth bass (coolwater/warmwater community)

iii) Extensive aquatic habitat surveys and fish collections carried out on much of the Rouge River over the past ten years provide a good database on this resource feature. Generally, aquatic habitats remain in relatively good condition in most sections of the river, with the above fish communities and indicator species being well represented in their respective preferred habitats.

1.3.3 Habitat Suitability Index (HSI) Modelling Results

(a) The appropriate HSI model for three of the indicator species was applied to the respective zones of the Rouge River to determine existing suitability of habitat conditions and potential impacts of future urban development scenarios.

(b) The headwaters currently have a poor to moderate HSI value (0.29) for brook trout limited primarily by the scarcity of adult habitat. This results in populations of small fish. Higher suitability habitats for brook trout are few and scattered, with many headwater stream habitats degraded by agricultural and residential development land uses. As a result, only remnants of a coldwater resident brook trout community remain on the Rouge River. Habitat factors sensitive to urbanization include baseflow, canopy cover, water temperatures and maintenance of a natural channel configuration.

(c) The midreaches have a high HSI value (0.78) for smallmouth bass. Habitat suitability is optimum in the more lacustrine habitats provided by ponds and reservoirs, such as the Milne Reservoir at Markham. It is anticipated that the development scenarios being considered could have a marginal effect on HSI values for bass. Onstream ponds could increase HSI by providing new lacustrine habitats, while increased sediment loading, higher suspended solids concentrations or increased fluctuations in water levels tend to lower HSI.

(d) Two HSI models were used to describe habitat suitability for rainbow trout in the lower reaches - one limited to seasonal migration on adult fish from Lake Ontario and the other for a natural, self-sustaining population in the river.

(e) The HSI for adult trout migration is high (0.88), confirming the suitability of the lower Rouge River for seasonal migration runs of not only rainbow trout, but also brown trout and chinook and coho salmon from Lake Ontario. These populations are sustained by annual stocking of hatchery-reared juvenile fish. Important habitat features for adult migration are not expected to be impacted by the urban development scenarios being examined.

(f) The HSI for a self-sustaining rainbow trout population in the lower Rouge River is 0.00, indicating several habitat limitations. A sensitivity analysis of the HSI model indicated that maximum summer water temperatures are excessive to support juvenile rainbow trout. A 2 to 4 degree Celsius reduction in maximum water temperatures results in an HSI value of 0.72 (good suitability), indicating that all other habitat criteria remain well suited for rainbow trout. Since Milne Reservoir is the controlling influence on water temperature entering the lower reaches of the main Rouge, it is expected that the development scenarios above Milne Reservoir will have little influence on HSI values for self-sustaining rainbow trout below the reservoir. There is some evidence that restoration of riparian vegetation and canopy shading of the lower river would achieve the desired decrease in maximum water temperatures and a substantial increase in HSI values. Other habitat variables which could be sensitive to future upriver urban development include baseflows, turbidity, sedimentation and channel scouring or bank erosion.

1.3.4 Aquatic Habitat Issues and Concerns

(a) There is concern that, at or beyond the predicted level of future development, physical habitats (i.e., channel morphology) in the lower reaches will deteriorate as a result of channel scouring and bank erosion. It is quite plausible that such physical habitat effects will exert a more substantial negative effect on fish populations than water quality effects of nutrients, trace metals and organics. This appears to have been a major factor in fish community losses in the Don River and Highland Creek as these watersheds were urbanized.

(b) Aquatic habitats in the Rouge watershed have, in large measure been buffered from development impacts because of physiography, topography and the historical pattern of development (i.e., mouth to headwaters). The Rouge has been only slightly influenced by sewage treatment facilities and combined sewer overflows which have caused major aquatic habitat degradation in other watercourses.

(c) Urbanization imposes other environmental risks which are difficult to quantify or predict. For instance, the incidence of accidental spills on roadways, at service stations or at industrial sites increases markedly with urbanization. As well, use of herbicides, pesticides, fertilizers and other chemical agents also imposes cumulative water quality stresses on receiving streams. Needless to say, a toxic material entering the river destroys habitat suitability for sensitive fish species regardless of the condition of other habitat criteria.

1.3.5 Recommended Strategy

(a) The HSI approach to determining acceptable habitat criteria for a target fish species should be applied on individual tributaries or specific river reaches which could be affected by a proposed development. In the Rouge Study, HSI's for the target species were applied to the average conditions found in large subsections of the watershed.

(b) Key habitat parameters and the resident fish community should be monitored on a regular basis to ensure that the fisheries objectives are being achieved. This will also provide useful data to refine and better adapt the HSI model as a useful watershed management tool in a Rouge River application.

1.4 WATER QUALITY

1.4.1 Introduction

In fulfilling its role as the watershed management agency, MTRCA is developing an integrated watershed management plan for the Rouge River watershed. As a part of this mandate, it is necessary to protect the quality of the water for purposes of public health, contact and non-contact recreation, protection of aquatic biota and aesthetics. As well, the effects of contaminant discharges upon the Lake Ontario ecosystem must be controlled.

To fulfil this mandate, the MTRCA with the assistance of the Ministry of the Environment (MOE) commissioned a study to examine present trends of water quality and to evaluate the need and effectiveness of water quality controls needed in rural and urban areas.

Water quality improvement could be achieved through:

(a) implementation of water quality controls in agricultural and urbanizing areas including the elimination of impacts of construction impacts;

(b) protection and extension of riparian vegetation which is fundamental to establishing good chemical and physical water quality for fish and other ecosystem values; and

(c) prevention of erosion, spills in new developments.

(a) Objectives

The purpose of the water quality component of the study was to assess the impact of urbanization upon the water quality of the Rouge River and to relate these impacts on fisheries and other end uses within the context of an Ecosystem Based Plan for water management.

The specific objectives of the water quality study were:

i) Assess historical water quality data in the Rouge River with a view to determining the effects of agriculture and the impacts of urbanization with respect to various quality related objectives and their exceedance.

ii) Evaluate water quality impacts upon fisheries habitat and scale to different levels of urbanization.

iii) Evaluate the generic truism that stormwater runoff from urban areas leads to degradation of stream quality (regular runoff, spills) and evaluate whether there is a need for water quality control in the Rouge River system.

iv) Examine control options (Best Management Practices: Structural, Non-Structural Methods) and their impact upon water quality.

v) Evaluate potential conflicts between the implementation of water quality control and other policies (including fisheries objectives; water quality control).

vi) Develop and evaluate new watershed management practices where warranted.

1.4.2 Statement of Conclusions

(a) General Study Findings

i) Prior to human settlement the Rouge River contained vast stands of forest. The spongy soil of these forests took up nutrients from the rainwater and soils and released other elements into the river. The soils released infiltrating rainwater over several hours to several days after a rainfall. Forest fires, hurricanes and other acts of nature historically caused periodic releases of nutrients and erosion of banks.

ii) Historically, development of the watershed has wrought major changes in the land use characteristics of the basin and the physical and hydraulic characteristics of the watercourse as a result of agriculture, urban development, tree harvesting and flood control. Land uses tended to be superimposed upon each other (in the same fashion as urban development is now superimposed on agricultural lands).

iii) The present water quality of the Rouge River is influenced by agricultural and other rural land uses (68%), small forest tracts (4%) and urban land uses (18%). The forested areas are primarily located in the headwaters and along valley lands in the lower watershed.

iv) Present monitoring data indicates that the river system:

   a) is non-turbid, except in the middle reaches and after rainfall;
   b) is eutrophic;
   c) has adequate oxygen resources;
   d) has moderate levels of bacterial counts;
   e) is probably non-toxic (based upon levels of metals); and
   f) has a temperature regime conducive to a warm water fishery.

Temperatures are conducive to cold water fisheries year round in the upper reaches which are still forested and in the other reaches during spring and fall.

v) Many microcontaminants, such as Synthetic Organic Chemicals (SOC's), are not easily monitored or modelled because they are undetectable or rarely detectable in surface waters, although they typically exist in any watercourse impacted by urban development and agricultural land use.

vi) The present water quality of the Rouge River requires improvement in order to meet provincial water quality objectives.

(b) Overview Based Upon Modelling and Other Predictive Tools

A number of models were used to assess the impact of urbanization upon water quality in the Rouge River watershed and evaluate the potential success of various remedial measures in minimizing these impacts. These conclusions are based upon the modelling results, monitoring data on the Rouge River watershed, and comparison of the Rouge River watershed with that of watersheds dominated by urbanization or agriculture.

i) Urbanization will have an impact upon the following water quality parameters:

- turbidity and suspended solids (including the effects of construction, bank erosion, and stormwater runoff);
- bacteria (eg. fecal coliforms);
- metals (eg. copper, lead, zinc); and
- parameters which characterize aesthetics (eg. colour).

ii) The frequency of spills from transportation and fixed sources increases in urban versus non-urban areas. In addition, increased human use of riparian habitats and wetlands in urban areas may impair their biological functions.

iii) Urban construction activities represent a substantial source of sediment and associated contaminant loading to watercourses.

iv) Structural measures and non-structural control options will improve the quality of stormwater runoff discharged from urban areas. Many of the most effective measures for controlling the above noted impacts (see i) are not being implemented in new urban areas.

v) The degree of urbanization is expected to allow dissolved oxygen to remain adequate for the stated fisheries objectives.

vi) The temperature of stormwater runoff will have a minimal impact upon the temperature of receiving waters, which is strongly influenced mainly by meteorological factors and canopy cover.

vii) Urbanization may or may not have a substantial impact upon water quality parameters such as BOD.

viii) The impact of urbanization upon synthetic organic chemicals (SOC's) resulting from herbicide/pesticide application needs to be more clearly documented.

1.4.3 Implications/Trends

(a) The study found that it was difficult to differentiate water quality impacts of rural and urban land uses in the Rouge River for conventional parameters such as suspended solids, total phosphorus, and nitrate by analysis of historical monitoring data or by using modelling studies. This is due to the inherent temporal variation of water quality parameters, a limited data base, and the small portion of the watershed which is predicted to urbanize.

It was not possible within the space of this study to predict impacts from construction activities and spills or to determine whether urbanization causes a seasonal loading of water quality parameters.

Stormwater runoff will contain a number of contaminants resulting from rainfall, overland soil erosion and urban activities (spills, construction). The need for water quality control must be based upon the expected water quality of stormwater.

(b) Temporary sediment controls on construction sites can mitigate overland sediment transport to watercourses, however, to be effective, enforcement of the controls must occur.

(c) Historical water quality control such as inspection programs to maintain sewer separation has been successful in improving water quality in the river for such parameters as BOD.

(d) In urban areas structural control measures such as wet ponds, filtration basins are currently the most effective means of approaching the degree of water quality improvements sufficient to sustain public health, recreation and aquatic ecosystem objectives.

1.4.4 Recommended Strategy

(a) Develop watershed based policies for urban stormwater management to improve the quality of stormwater.

(b) Master Drainage Plans should include the following objectives (where they are applicable):

- Flood Control
- Erosion Control
- Fisheries
- Water Quality
- Terrestrial Habitat
- Riparian Habitat

(c) A comprehensive program to mitigate water quality impacts from rural land use practices and to rehabilitate riparian habitats on rural lands should be developed and implemented. The program would include measures such as:

- o Best Management Practices to reduce soil erosion; nutrient, herbicide and pesticide leaching bacterial releases, and other problems from farming operations;
- o elimination of livestock accessto the watercourse;
- o streambank erosion control.

(d) The following control measures and policies should be implemented on a watershed basis in urbanizing areas to achieve a substantial improvement of urban stormwater quality discharged to the receiving water.

- o control structures which promote infiltration of stormwater (eg. infiltrations galleys, infiltration trenches, soakway pits);
- o multi-use wet ponds and extended wet ponds which provide runoff control, warm water fish habitat, waterfowl habitat, recreation and aesthetics.

(e) The following municipal and/or conservation programs should be implemented on a watershed wide basis to provide improvements in quality of urban stormwater:

- o Urban maintenance measures (catchbasin, poop and scoop programs, street sweeping, leaf collection).
- o Municipal programs (Enforcement of municipal by-laws).

- o Vegetative best management practices (filter strips, grassed swales, riparian vegetated strips, revegetation of denuded areas).

(f) There is a need to control spills. This can be accomplished through programs and structural designs, including:

- o the largest impact related to flushing of spills by fire departments can be mitigated by enhancing cooperative programs between the Ministry of the Environment and fire departments. Such programs should include:

  i) education of fire department and others regarding the handling of toxic materials;

  ii) simultaneous arrival times of environmental and fire departments at the spill location. This would ensure that both the fire department and the Ministry of the Environment - Spills Management Team are simultaneously informed of the spill to provide a more coordinated attack can occur.

  iii) changes in practice:
    - o protocol for handling different types of spills;
    - o collection of spillage/sorbants and treatment.

    - o installation of API type, oil-water separators upon catchbasins draining industrial areas where petrochemicals are used;

    - o inspection of industries to ensure that floor drains receiving spillage of pollutants from normal practices are either connected to the sanitary sewer system or lead to a water treatment system before discharge. This could include the Ministry of the Environment's Model Sewer Use By-Law.

(g) All construction in newly developing areas should have temporary setting ponds which minimize suspended solids discharge, These ponds must be inspected to ensure that they function properly.

(h) Existing provincial/municipal programs for preventing the discharge of combined sewer overflows, and STP discharges should be continued. If any new STP's are constructed in the future, suitable technology should be employed to aid the attainment of Provincial Water Quality Objectives in the Rouge River Basin.

(i) Mechanisms need to be established for ensuring implementation of these strategies and for auditing their performance on an ongoing basis.

(j) Additional studies (outside the scope of the Rouge drainage Study) are required to aid the development of site specific policies and to address deficiencies in the present modelling and monitoring data base. These studies include:

o groundwater quality in the watershed. The present quantitative models for the most part describe the general occurrence and flow of water in aquifers; whereas what is needed to mitigate any groundwater impacts from urbanization is precise quantitative models of contamination occurrence and transport;

o evaluating best management practices. Specific studies are required to:

- validate performance predictions with monitoring data;
- assess conflicts associated with other Best Management Practices; and

- develop criteria for regulatory authorities to use in their assessment of proposed water quality management practices.

o monitoring data deficiencies:

- assessment of Synthetic Organic Chemicals (SOC's) in the Rouge River system;
- measurement of instream sediment contaminant concentrations;
- measurement of fish contaminant levels;
- evaluation of any transmittable diseases in the present fishery;
- leachate quality from existing landfills; and
- toxicity monitoring.

(k) Design of all mitigative and remedial works for flood and erosion control should be cognizant of the fisheries, terrestrial and water quality objectives and their design criteria should be incorporated where appropriate.

(l) Guidelines for design of the most effective water quality co1ntrol facility(ies) (i.e., passive wet ponds, infiltration trenches) should be prepared based on existing technology. These guidelines should be updated as new technology and data is learned.

1.5 TERRESTRIAL HABITAT

1.5.1 Introduction

One of the objectives of the Rouge River Watershed Urban Drainage Study was to review all available data on terrestrial resources in the valleys of the Rouge drainage basin.

The results of this review are summarized below into four biophysical zones and their corresponding land uses and environmental sensitivities (see Table 1).

Also reviewed and updated were environmentally significant areas criteria based on more current classifications.

A second objective was to develop a framework for the terrestrial impact assessment of hydrologic-related changes predicted for alternative planning scenarios.

There exist five areas that are potentially most sensitive to hydrologic changes: Lower Rouge Marshes, Meander Scar on Rouge River between Kingston Rd. and Twyn Rivers Dr., Morningside Tributary/Rouge River Confluence, Tabors Meadow on the Little Rouge River, Unionville Marsh on Bruces Creek just above its junction with Rouge River.

The five sites selected as indicator areas were sensitive to hydrological-related changes resulting from urban drainage management alternatives (water quantity/quality, seasonal changes in flow, flooding, erosion).

TABLE 1

BIOPHYSICAL ZONES

Zone	Biophysical Designation (Chapman and Putnam, 1984)	Terrestrial Environment Zone	Aquatic Habitat Zone	Characteristics
1	Kame Moraine	Oak Ridges Moraine	Headwater Tributaries	Rolling upland: rural estate, natural
2	Till Plain	Open field, minimal forested valley	Middle Reaches	Flat: rural, agricultural
3	Sand Plain (below Lake Iroquois shoreline)	Rouge Forest	Lower Reaches	Flat with deeply incised valleys; urban uplands, natural valleys
4	Clay Plain	Rouge Marsh	Delta Marsh	Flat marsh, natural with encroaching urban

Selection of the criteria include the following:

(a) Rare Species Protection

Rare species used in sensitive areas are generally plants. Plants are stationary, thus are more vulnerable to hydrologic related impacts than wildlife, i.e., Lower Rouge Marsh.

(b) Habitat Protection

Determination of the portion of the critical habitat with potential impact is found by airphotos and map analysis, supplemented by field reconnaissance. Possible impacts may be changes in river course, flooding, changes in erosion or water chemistry.

(c) Erosion/Deposition Zone

Many sensitive riparian habitats are affected by either lessening of the erosion/deposition (allowing succession to replace the plant types found) or increased erosion and sediment movement (eliminating the habitat or moving it downstream).

(d) Valley System - Land Use/Recreational Values

Potential impacts of urban drainage alternatives on the valley system as a whole were examined for how they impacted aesthetics, wildlife corridors, recreational and other resources uses. Areas where hydrologic related changes might either detract from or enhance existing uses were ranked according to the significance of the impacts on this use.

1.5.2 Impact Assessment

(a) Lower Rouge Marshes

The Lower Rouge Marsh is sensitive to water level changes; due to the restrictions these changes impose on macrophyte growth and survival. The habitat is also sensitive to nutrient loading which could stimulate plant growth thus closing in the marsh, affecting its habitat potential. Marsh vegetation could also be impacted if sediment loads in the river increase significantly resulting in deposition in the quiescent marsh areas to the extent that vegetation is smothered. This area is a habitat for rare aquatic species. An extended period of time increase in water level may affect this area.

(b) Meander Scar

This erosion sensitive area would be impacted by increased erosion. Increased flows and/or velocity would accelerate erosion at the scar and downstream.

(c) Morningside-Rouge Confluence

This deeply incised valley has several erosion features and diverse ecological values. The Morningside-Rouge confluence is an important wildlife corridor. Currently the area is highly developed and provides a measure of the impact of urbanization.

(d) Tabor's Meadow

This meadow is a floodplain and, therefore, would be affected by any hydrologic related changes. Assessment must consider off-road vehicle scars, tree planting impacts and impacts from the Beare Road Landfill. Erosion scars both upstream and in the Twyn Rivers Road area downstream are also sensitive features.

Erosion deposition in this wet-meadow, riparian area maintains its early succession stages. Decreased erosion will result in establishment of vegetation from later succession stages. Increased erosion would either smother the vegetation or, if flows are greater, result in the sediment bed load being deposited further downstream and the wet-meadow gradually eroding away without being replaced.

(e) Unionville Marsh

Macrophytes are sensitive to water level or flow changes. However, with a downstream control dam and the current level of development in the area, impact potential is lessened. This does raise the potential for increased sediment deposition and nutrient loading which could either increase the density of macrophytes or smother them.

1.5.3 Historic Airphoto Analysis

Historical data consists of aerial photographs taken in 1954 and 1978 which gives an excellent overview of the impacts of urbanization.

(a) Rouge Marsh

Changes since 1954 are dramatic. Urban development has replaced the fields, leaving the marsh surface drainage area mostly impervious, resulting in larger and shorter duration spring or storm flows which lessen base flow during dry periods. Water level is influenced more by Lake Ontario levels. A second significant change is the disappearance of development in the valley and marsh.

(b) Whitby Formation Erosion Scars

Between 1954 and 1978 this area underwent significant and dramatic changes. Within the valley complex, the vegetative cover has increased significantly. River morphology has significantly changed from 1954 through 1978. The river in 1978 appears to follow a deeper, narrower channel. Erosion scars are greater and the river straightened. Urbanization has filled in areas to the south of the river. The Little Rouge Forest to the northeast has increased significantly in forest cover since 1954.

(c) Morningside-Rouge Confluence

Significant industrial development to the south and the Metro Zoo to the north of this area has occurred. Increases in surficial runoff since 1954 are indications of the river becoming straighter, narrower and deeper.

(d) Tabor's Horsetail Meadows

The meadow is affected by a number of major developments: Beare Road Landfill site and railway right-of-way. Vehicles travelling on the right-of-way have forded the river, resulting in significant bank erosion. Increasing runoff flow has resulted in a narrower, deeper, faster flowing river section which has increased upstream erosion scars and straightened the river.

(e) Unionville Marsh

There existed two changes apparent by 1978: one, urbanizational change is significant and two, probable increase in sedimentation and nutrient loading has shown signs of infilling of the marsh area by cattails and vegetation.

1.5.4 Hydrological Modelling Summary

(a) Velocity changes are negligible in marsh sites, however, the river sections with steeper gradient and greater erosion potential are 0.1 to 0.2 cm/s (Table 2). Increase in velocity was found to increase erosion potential.

(b) River volume increases are minimal at the marsh sites, but are predicted to increase in the faster flow reaches. This may also increase erosion.

(c) Significant velocity changes between the existing or committed development scenario and high density scenario existed at the Morningside Confluence and Tabors Meadow. High development could result in increased erosion.

1.5.5 Conclusions

(a) While changes will occur in riparian habitat, past changes are not measurable and, therefore, difficult to predict.

(b) The amount of terrestrial cover does not appear to have changed significantly since 1954.

(c) The Rouge Marsh has not been affected by increased flows of the watershed, but is influenced by the water levels of Lake Ontario.

(d) Steeper gradient in lower reaches all show signs of increased river flows resulting in more significant erosion scars, deeper, narrower and straighter river channels and reduction of meanders.

(e) Unionville Marsh shows signs of increased sedimentation and nutrient loading since 1954. These are a result of long-term agricultural land use rather than urban surface drainage.

TABLE 2

EXISTING, HISTORICAL AND PREDICTED FLOWS AT TEST SITES.
PREDICTIONS ARE AT 95% CONFIDENCE LEVEL
(e.g., 95% of flows will be less than this number)

Test Site	Hydrological Study Reference	Hurricane Hazel		High Development		Medium Development	
		Volume (m3/s)	Velocity (cm/s)	Volume (m3/s)	Velocity (cm/s)	Volume (m3/s)	Velocity (cm/s)
A. Rouge Marsh	26.1	257.8	2.2	17.0	0.5	15.0	0.5
B. Erosion Scar	15.1	167.9	3.3	8.5	1.0	8.5	1.0
C. Morningside-Rouge	14.0	16.8	1.9	3.0	1.2	3.0	1.2
D. Tabor's Meadow	25.0	87.5	2.2	6.5	0.9	5.0	0.8
E. Unionville Marsh	10.1	52.2	0.9	4.0	0.5	4.0	0.5

Test Site	Committed Development		Existing Development	
	Volume (m3/s)	Velocity (cm/s)	Volume (m3/s)	Velocity (cm/s)
A. Rouge Marsh	15.0	0.5	15.0	0.5
B. Erosion Scar	8.5	1.0	7.0	0.9
C. Morningside-Rouge	2.0	1.0	1.4	1.0
D. Tabor's Meadow	4.5	0.7	4.5	0.7
E. Unionville Marsh	4.0	0.5	4.5	0.5

1.5.6 Recommended Strategy

(a) A monitoring program of significant terrestrial habitats be established. This program would utilize existing data and document the accuracy of the hydrological predictions and measure the effects on these habitats.

(b) Accelerate existing naturalization program to establish a riparian habitat zone along all watercourses.

(c) Establish public education awareness and private lands stewardship programs to protect, enhance and manage terrestrial and riparian habitats.

(d) Establish a land acquisition program to protect lands containing important floral and faunal features.

APPENDIX 4

APPENDIX 4

FEDERAL GUIDELINES
FISH CONSUMPTION LEVELS

	Women (Child Bearing) Children Under 15 Years	Adults	NOT Consumed
MERCURY	< 0.5 ppm	0.5 - 1.5 ppm	> 1.5 ppm
PCB	< 2.0 ppm	> 2.0 ppm	-----
MIREX	< 0.1 ppm	> 0.1 ppm	-----
DDT	< 5.0 ppm	> 5.0 ppm	-----
DIOXIN	< 20.0 ppt	> 20.0 ppt	-----

* The consumption guidelines developed for use by Ontario's Anglers are based on Federal guidelines supplemented by consumption recommendations prepared by the World Health Organization. - From "Guide to Eating Ontario Sport Fish, 1988".

APPENDIX 5

APPENDIX 5

MINISTRY OF THE ENVIRONMENT
DRINKING WATER OBJECTIVES

MAXIMUM ACCEPTABLE CONCENTRATIONS
PARAMETERS RELATED TO HEALTH

PARAMETER*	CONCENTRATION (mg/L)
Arsenic	0.05
Barium	1.0
Boron	5.0
Cadmium	0.005
Chromium	0.05
Cyanide (Free)	0.2
Fluoride	2.4
Lead	0.05
Mercury	0.001
Nitrate (as N)**	10.0
Nitrite (as N)	1.0

* Unless otherwise stated the limits for each substance refer to the sum of all forms present.

** Where both nitrate and nitrite are present, the total nitrate plus nitrite-nitrogen should not exceed 10 mg/L.

APPENDIX 5 (cont'd.)

MAXIMUM DESIRABLE CONCENTRATIONS
PARAMETERS RELATED TO AESTHETIC QUALITY

PARAMETER	CONCENTRATION*
Chloride	250
Colour	5 (TCU)**
Copper	1.0
Iron	0.3
Manganese	0.05
Methane	3 L/cu. m
Odour	Inoffensive
Organic Nitrogen***	0.15
Phenols	0.002
Sulphate	500
Sulphide	Inoffensive
Taste	Inoffensive
Temperature	15°C
Total dissolved Solids	500
Total Organic Carbon	5.0
Zinc	5.0

* Unless otherwise indicated, the maximum desirable concentrations are expressed in mg/L

** True Colour Units

***Total kjeldahl nitrogen minus ammonia nitrogen.

Summary Table of Drinking Water Objectives from Water Management Goals, Procedures, Objectives and IMplementation Procedures of the Ministry of the Environment, 1984.

APPENDIX 6

APPENDIX 6

MINISTRY OF THE ENVIRONMENT
PROVINCIAL WATER QUALITY OBJECTIVES

INORGANIC AND OTHER

SUBSTANCE	LEVEL NOT EXCEEDED
pH	6.5 - 8.5
unionized ammonia	0.02 mg/L (to protect aquatic life)
chlorine	0.002 mg/L
cyanide	0.005 mg/L
dissolved gases	110%
hydrogen sulphide	0.002 mg/L (to protect aquatic life)
oil and grease	should not exceed levels which create: visible film, sheen or discoloration, odour could cause tainting or edible aquatic organisms or cause deposits
phosphorus (general guidelines)	30 ug/L
HEAVY METALS	
arsenic	100 ug/L (to protect aquatic life)
beryllium	11 ug/L (unfiltered sample of hardness 75 mg/L of $CaCO^3$) 1100 ug/L (unfiltered sample of hardness 75 mg/L $CaCO^3$)
cadmium	0.2 ug/L (to protect aquatic life)
chromium	100 ug/L (to protect aquatic life)
copper	5 ug/L (to protect aquatic life)
iron	300 ug/L (to protect aquatic life)
mercury	0.2 ug/L
nickel	25 ug/L (to protect aquatic life)
selenium	100 ug/L (to protect aquatic life)
silver	0.1 ug/L (to protect aquatic life)
zinc	30 ug/L (to protect aquatic life)

APPENDIX 6 (cont'd.)

PROVINCIAL WATER QUALITY OBJECTIVES
SWIMMING AND BATHING USE OF WATER

AESTHETICS	The water should be devoid of debris, oil, scum and any substance which would produce an objectionable deposit, colour, odour, taste or turbidity.
DISCHARGE OF WASTE MATERIALS	Must be curtailed or controlled in order to maintain recreational usage.
pH	pH of water used for recreational purposes should be within the range of 6.5 - 8.5.
WATER CLARITY	Should be sufficiently clear to estimate depth or to see submerged swimmers. (Secchi disc transparency of at least 1.2 m)
PUBLIC HEALTH CONSIDERATIONS	Water should not cause disease(s) or infection(s) as a result of pathogens, including bacteria, fungi, protozoa or viruses. Fecal coliforms should not exceed 100/100 ml.

Summary Table of Provincial Water Quality Control Objectives from Water Management Goals, Policies, Objectives and Implementation Procedures of the Ministry o f the Environment, 1984.

APPENDIX 7

FWS/OBS-82/10.36
September 1983

HABITAT SUITABILITY INFORMATION: SMALLMOUTH BASS

by

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PREFACE

The Habitat Suitability Index (HSI) models presented in this publication aid in identifying important habitat variables. Facts, ideas, and concepts obtained from the research literature and expert reviews are synthesized and presented in a format that can be used for impact assessment. The models are hypotheses of species-habitat relationships, and model users should recognize that the degree of veracity of the HSI model, SI graphs, and assumptions will vary according to geographical area and the extent of the data base for individual variables. After clear study objectives have been set, the HSI model building techniques presented in U.S. Fish and Wildlife Service (1981) and the general guidelines for modifying HSI models and estimating model variables presented in Terrell et al. (1982)[2] may be useful for simplifying and applying the models to specific impact assessment problems. Simplified models should be tested with independent data sets, if possible.

A brief discussion of the appropriateness of using selected Suitability Index (SI) curves from HSI models as a component of the Instream Flow Incremental Methodology (IFIM) is provided. Additional SI curves, developed specifically for analysis of smallmouth bass habitat with IFIM, also are presented.

This model has not been tested against field data. Model reliability is likely to vary in different geographical areas and situations. The U.S. Fish and Wildlife Service encourages model users to provide comments, suggestions, and test results that may help us increase the utility and effectiveness of this habitat-based approach to impact assessment. Please send comments to:

Habitat Evaluation Procedures Group or Instream Flow
    and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Ft. Collins, CO 80526-2899

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[1] U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

[2] Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Fish Wildl. Serv. FWS/OBS-82/10.A. 54 pp.

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SMALLMOUTH BASS (Micropterus dolomieui)

HABITAT USE INFORMATION

General

The original range of the smallmouth bass (Micropterus dolomieui) extended from the Great Lakes south to northern Georgia and Alabama, east to the Appalachian range, and west to eastern Oklahoma (MacCrimmon and Robbins 1975; Lee et al. 1980). The species has been widely introduced outside of this range in the Northeast and areas west of the Mississippi drainage (Lee et al. 1980). Two subspecies are recognized: (1) the northern smallmouth (M. d. dolomieui) of the Great Lakes and adjacent regions (Hubbs and Bailey 1940); and (2) the Neosho smallmouth (M. d. velox) of northwestern Arkansas, northeastern Oklahoma, and southwestern Missouri (Hubbs and Bailey 1940; Ramsey 1975).

Age, Growth, and Food

Age at sexual maturity of smallmouth bass varies throughout its range and is related to latitude and to the growth rate of local populations (Robbins and MacCrimmon 1974). Males and females mature at age II in the South and at age VI in the North (Fraser 1955; Harlan and Speaker 1969; Turner and MacCrimmon 1970). In the central part of the range, males usually mature at age III-IV (about 25 cm), and females usually mature at age IV or V (30 cm) (Stone et al. 1954; Webster 1954; Fraser 1955; Latta 1963; Pflieger 1975).

Although a 15-year old smallmouth bass has been recorded (Scott and Crossman 1973), fish older than 7 years are uncommon (Robbins and MacCrimmon 1974). Adults are usually 20-56 cm long. The largest recorded smallmouth bass was a 5.4 kg, 68.6 cm long fish from Kentucky (Anonymous 1972).

The diet of smallmouth bass changes from small to large food items as the fish grow. Fry feed on microcrustaceans (Beeman 1924; Applegate et al. 1967). Juvenile smallmouth bass eat larger insects, crayfish, and fish (Doan 1940; Webster 1954). Adults primarily feed on fish and crayfish in both lakes and streams (Tester 1932; Doan 1940; Tate 1949; Webster 1954; Reynolds 1965). The diet is influenced by abundance (Paragamian 1973) and availability of prey (Coble 1975).

Reproduction

Smallmouth bass spawn in spring, usually mid-April to July (Watson 1955; Henderson and Foster 1957; Harlan and Speaker 1969; Turner and MacCrimmon 1970; Smitherman and Ramsey 1972; Neves 1975; Pflieger 1975), depending on geographical location and water temperature. Cleary (1956) observed a 45 day post-nesting period for smallmouth spawning in Iowa streams.

Smallmouth bass spawn on rocky lake shoals, river shallows, or backwaters or move into creeks or tributaries to spawn (Harrison 1954; Webster 1954; Cleary 1956; Sanderson 1958; Harlan and Speaker 1969; Coble 1975; Clancey 1980). Smallmouth bass spawned in warm sloughs or backwater areas bordering the Columbia River (Montgomery et al. 1980). The species requires a clean stone, rock, or gravel substrate for spawning (Robbins and MacCrimmon 1974). Studies show that the habitat condition during spawning is the most important factor for year class strength in smallmouth bass (Clancey 1980).

Nest building and spawning occur when the water temperature is 12.8-21.0° C (Turner and MacCrimmon 1970; Scott and Crossman 1973; Shuter et al. 1980), but most activity occurs at or above 15° C (Henderson and Foster 1957; Latta 1963; Harlan and Speaker 1969; Coble 1975; Shuter et al. 1980).

Specific Habitat Requirements

Optimum riverine habitat is characterized by cool, clear, midorder streams > 10.5 m wide (Carlander 1977) with abundant shade and cover (Larimore et al. 1952) and deep pools, moderate current, and a gravel or rubble substrate (Sanderson 1958; Robbins and MacCrimmon 1974; Coble 1975; Pflieger 1975). Streams with gradients of 0.75-4.70 m/km, that provide alternating pools and riffles, support the largest stream populations of smallmouth bass (Trautman 1942; Hallam 1959; Robbins and MacCrimmon 1974; Coble 1975; Funk and Pflieger 1975). Standing crop is generally largest in pools deeper than 1.2 m (Robbins and MacCrimmon 1974; Paragamian 1979; Clancey 1980).

Growth of smallmouth bass is faster in lakes and reservoirs than in rivers (Robbins and MacCrimmon 1974). Optimum lacustrine habitat is characterized by large, clear lakes and reservoirs with an average depth greater than 9 m with rocky shoals (Turner and MacCrimmon 1970; Coble 1975; Miller 1975; Pflieger 1975). Large concentrations of smallmouth bass occurred over a broken rock and boulder substrate with a large amount of interstitial space in the Tongue River Reservoir in Montana (Penkal and Gregory 1980). No bass were found over a rounded rock substrate or sand in the Snake River (Munther 1970). Although smallmouth are able to live in small ponds (Bennett 1965; Buck and Thoits 1970; Coble 1975), populations are more successful in larger lakes and reservoirs (Jenkins 1975). Smallmouth are found almost exclusively in the epilimnion during summer stratification in northeastern Wisconsin and Ontario (Hile and Juday 1941; Turner and MacCrimmon 1970), yet frequent depths up to 12 m in all seasons in northern New York (Webster 1954).

Smallmouth bass exhibit strong, cover-seeking behavior and prefer protection from light in all life stages (Coble 1975; Miller 1975). Deep, dark quiet water is used for cover (Coble 1975), but bass use all forms of submerged cover, such as boulders, rocks, stumps, root-masses, trees, and crevices, without apparent preference for any one type (Larimore et al. 1952; Hubert and Lackey 1980).

Smallmouth occur at pH levels of 5.7 (Clady 1977) to 9 (Paragamian 1979), although optimum pH is 7.9-8.1 (Funk and Pflieger 1975). Butler (1972) found that smallmouth bass cover-seeking behavior was reduced at pH levels < 6, and the lower lethal pH level was 3.

Smallmouth bass populations are more productive in clearer, less fertile reservoirs several years after impoundment that have low total dissolved solids (TDS = 100-350 ppm) (Jenkins 1975, 1976).

Smallmouth require more than 6 ppm dissolved oxygen (D.O.) for optimal growth (Bulkley 1975). Production rates are reduced by 10% when the amount of oxygen is lowered to 3 ppm at 15° C; production rates are reduced by 20% if oxygen is lowered to 4 ppm at 20° C (Bulkley 1975). Smallmouth bass frequently die at DO concentrations approaching 1 ppm at 20-25° C (Burdick et al. 1954; Bulkley 1975).

Smallmouth bass apparently can tolerate periodic turbidity (Webster 1954; Cleary 1956), although excessive turbidity and siltation will reduce a population (Coutant 1975). Hubert and Lackey (1980) reported a typical smallmouth bass habitat to have very low turbidity, usually ≤ 25 JTU, and almost never > 75 JTU (except under flood conditions when turbidity is sometimes as high as 250 JTU).

Adult. In streams, adults occupy pools or deep areas behind rocks where there is no perceptible current (Keating 1970; Munther 1970; Funk and Pflieger 1975; Pflieger 1975). Adults are often near the edge of the current during the day (Cleary 1956; Munther 1970). Movement of adults in streams is restricted during a single season to a single pool (Funk 1957; Brown 1961; Fajen 1962; Munther 1970; Montgomery et al. 1980).

In lakes and reservoirs, adults most often use cooler areas, such as dropoffs, that are away from vegetation and in water < 12 m deep (Scott and Crossman 1973; Coble 1975). In a Tennessee River reservoir, adults were frequently in water > 10 m deep during the summer (Hubert and Lackey 1980). Seasonal mean current velocity in bass habitats during the study varied from 10.9 to 32.0 cm/sec.

Temperatures may be the most important single factor limiting distribution of smallmouth bass (Robbins and MacCrimmon 1974; Coutant 1975). Faster growth rates of adult smallmouth bass are generally associated with higher summer temperatures (Doan 1940; Brown 1961; Forney 1972). Faster growth rates occur in southern reservoirs, resulting in earlier death than in northern regions (Coutant 1975). In the summer, bass inhabit warmer shoreline areas of large lakes in the North and deeper, cooler waters in the South (Coutant 1975). Growth does not begin until water temperatures reach 10-14° C (Coble 1975). Field data indicate that adults prefer temperatures of about 21-27° C in the summer (Clancey 1980). Smallmouth bass have been reported "sunning" themselves in pools with water temperatures of about 26.7° C in summer (Munther 1970).

Temperature preferences of smallmouth bass vary considerably depending on the acclimation temperature (Ferguson 1958; Cherry et al. 1975; Coutant 1975). Smallmouth bass acclimated at 2.2-30.0° C selected temperatures of 20-32° C in laboratory tests (Mathur et al. 1981). Adult bass in the laboratory preferred temperatures of 28° C (Ferguson 1958; Bennett 1965) to 31° C (Barans and Tubb 1973; Coutant 1975). Optimum growth rates in the lab occurred at temperatures from 26-29° C (Peek 1965; Shuter et al. 1980; Wrenn 1980). Upper lethal temperatures for adults were above 32.3° C (Coble 1975).

When temperatures drop to 15-20° C, adults seek deep, dark areas (Webster 1954; Munther 1970). At about 10° C, bass become inactive and seek shelter (Coble 1975; Shuter et al. 1980). At 6-7° C, most smallmouth bass are beneath the rock substrate, with few remaining on top (Munther 1970). The lower lethal temperature is near freezing (Coble 1975). Bass will congregate around warm springs in winter when available (Coutant 1975).

Embryo. Nests are usually in water from 0.3-0.9 m deep (Coble 1975), but may be built in water up to 7 m deep (Mraz 1964; Robbins and MacCrimmon 1974). Nests are commonly in gravel or broken rock (Latta 1963; Mraz 1964); near boulders, logs, or other cover (Scott and Crossman 1973); in shallows or backwaters of streams (Clancey 1980); or in protected bays or shoals in lakes (Robbins and MacCrimmon 1974). Nests are also made over bedrock, rootlets in silt, or sand, but these substrates are less commonly used (Cleary 1956; Latta 1963; Scott and Crossman 1973). Nests are usually in areas of quiet water (Pflieger 1975) or very slow current (Robbins and MacCrimmon 1974).

Embryos develop normally at temperatures from 13-25° C (Webster 1954; Coble 1975). Extreme fluctuations in temperature cause embryo mortality from acute thermal shock (Webster 1954; Montgomery et al. 1980) or will cause males, the caretakers, to leave the nest unprotected from predators and/or fungus may grow (Cleary 1956; Watt 1959). There may be another spawning period if there is a sudden drop in temperature during the first attempt.

In a laboratory study, 42% of the embryos survived more than 14 days at 4.4 ppm dissolved oxygen and 20° C; none survived at D.O. levels < 2.5 ppm (Siefert et al. 1974). It is assumed that D.O. levels > 6 ppm are necessary for maximum embryo survival (Bulkley 1975).

Large fluctuations in water level can affect reproductive success (Pflieger 1975; Montgomery et al. 1980). Ideal spawning conditions include one or more substantial rises in water level a week or two prior to bass nesting (Pflieger 1975) and relatively stable water levels while nesting is in progress (Watson 1955; Pflieger 1975). Rising water may flush nest areas with cold water, causing nest desertion and halting embryo development (Watt 1959; Montgomery et al. 1980). Falling water levels may drive guarding males off, limit water circulation around eggs, and increase predation, resulting in lower reproductive success (Neves 1975; Montgomery et al. 1980).

Fry. Smallmouth bass fry grow faster at higher temperatures (Shuter et al. 1980). The optimum temperature range for growth in the laboratory was 25-29° C (Munther 1970; Shuter et al. 1980). Fry inhabit areas with near optimum temperatures in summer (Coutant 1975), using calm, shallow, marginal areas with rocks and vegetation (Paragamian 1973; Coble 1975). Growth of fry ceases at 35° C (Shuter et al. 1980), and the upper lethal temperature is about 38° C (Larimore and Duever 1968).

Activity levels of fry drop at 20° C (Coble 1975), and swimming is greatly reduced at 10° C (Larimore and Duever 1968; Pflieger 1975). Fry seek rocky shelters in littoral or shore areas when the water is 7° C (Webster 1954; Keast 1968). The lower lethal temperature for fry is about 4° C (Larimore and Duever 1968). There is generally high winter mortality of fry, especially in northern areas; size of the fish and the length of hibernation determines their survival (Oliver et al. 1979; Shuter et al. 1980).

Fry seem to be especially vulnerable to flood conditions and fluctuating water levels (Larimore 1975). A rapid drop in water level may trap them in areas where they will become dessicated (Montgomery et al. 1980). A stream rise of only a few inches may displace advanced fry newly risen from the nest (Webster 1954). Most fry remain in shallow water (Doan 1940; Forney 1972), although some may be found at depths of 4.6.-6.1 m (Stone et al. 1954; Forney 1972). Fry 20-25 mm in length cannot maintain themselves in current velocities > 200 mm/sec (Larimore and Duever 1968). An increase in turbulence during flood conditions creates conditions with which smallmouth fry appear unable to cope (Webster 1954). Fry cannot tolerate and are displaced at high turbidities (2,000 JTU) combined with an increase in water velocity, but they will not be displaced at moderate turbidities (250 JTU) (Larimore 1975). Low water temperatures during flood conditions will reduce fry swimming ability (Larimore and Duever 1968).

Fry cease feeding at dissolved oxygen levels < 1 ppm (Bulkley 1975), and survival is low at levels < 2.5 ppm (Siefert et al. 1974). Levels > 6 ppm are considered optimum.

Juvenile. Juveniles spend most of their time in quiet water near or under a dark shelter, such as brush or rocks (Reynolds 1965; Paragamian 1973, 1979). Juvenile and adult smallmouth bass both prefer low velocity water near a current, but juveniles are often found in slightly shallower water than adults.

In laboratory studies, juveniles preferred temperatures of about 28° C (Coutant 1975) to 31° C (Barans and Tubb 1973). Maximum growth occurred at 25-29° C (Horning and Pearson 1973; Cherry et al. 1975; Shuter et al. 1980; Wrenn 1980). The upper lethal temperature for juveniles is about 35° C (Cherry et al. 1975). Activity is reduced below 20° C (Coble 1975) and little growth occurs below 16° C (Horning and Pearson 1973). Juveniles seek shelter in the crevices and fissures of the rock substrate at very low temperatures (below 7.8° C) (Munther 1970), and the lower lethal temperature occurs near freezing (Horning and Pearson 1973).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Geographic area. The model is applicable throughout the native and introduced range of smallmouth bass in North America. The standard of comparison for each individual variable suitability index is the optimum value of the variable that occurs anywhere within the native and introduced range of the species. For example, the model may never provide an HSI of 1.0 when applied to water bodies in northern areas where temperature related variables do not reach the optimum values of more southern locations.

Season. The model provides a rating for a water body based on its ability to support a reproducing population of smallmouth bass through all seasons of the year. The model will provide an HSI of 0.0 if the Suitability Index (SI) for any reproduction related variable indicates that the species is not able to reproduce in the habitat being evaluated.

Cover types. The model is applicable in riverine and lacustrine habitats as described by Cowardin et al. (1979).

Minimum habitat area. Minimum habitat area is defined as the minimum area of contiguous habitat that is required for a species to live and reproduce. No attempt has been made to establish a minimum habitat size for smallmouth bass.

Verification level. The acceptance goal of the smallmouth bass model is that the model produces an index between 0 and 1 that appears to have a positive relationship to spawning success and carrying capacity for fry, juveniles, and adults. In order to verify that the model output was acceptable, HSI's were calculated from sample data sets. These sample data sets and their relationship to model verification are discussed in greater detail following the presentation of the model.

Model Description - Riverine

The analysis of the quality of smallmouth bass habitat is based on an evaluation of the ability of the habitat to meet the requirements for food, cover, water quality, and reproduction. Habitat variables that affect growth, survival, abundance, or other measures of well-being of smallmouth bass are placed in the appropriate model component (Figs. 1 and 2).

Food component. Substrate type (V_1) is assumed to be important in relation to food production. Crayfish are a large part of the adult diet, and they usually live on rocky substrates. Some studies have indicated that the preference of smallmouth bass for a certain substrate is related to food production. Percent pools (V_2) is included because smallmouth bass occupy pools almost exclusively in rivers. Percent cover (V_6) is included because cover, such as stumps, trees, boulders, and crevices, is related to the production of adult food (crayfish and small fish).

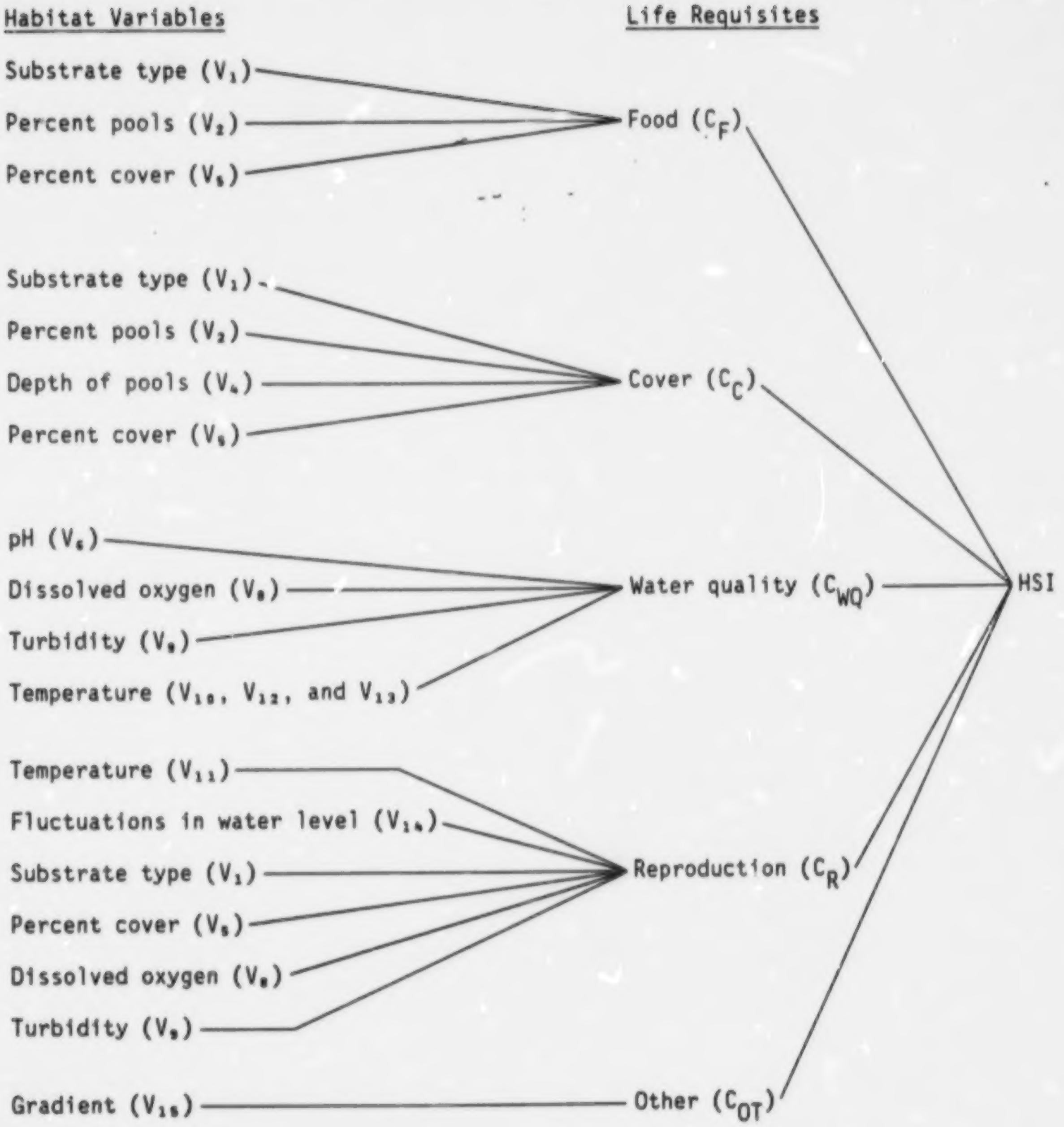

Habitat Variables
Life Requisites
Substrate type (V_1)
Percent pools (V_2)
Percent cover (V_5)
Food (C_F)
Substrate type (V_1)
Percent pools (V_2)
Depth of pools (V_4)
Percent cover (V_5)
Cover (C_C)
pH (V_6)
Dissolved oxygen (V_8)
Turbidity (V_9)
Temperature (V_{10}, V_{12}, and V_{13})
Water quality (C_{WQ})
HSI
Temperature (V_{11})
Fluctuations in water level (V_{14})
Substrate type (V_1)
Percent cover (V_5)
Dissolved oxygen (V_8)
Turbidity (V_9)
Reproduction (C_R)
Gradient (V_{15})
Other (C_{OT})

Figure 1. Tree diagram illustrating relationships of habitat variables and life requisites in the riverine model for the smallmouth bass.

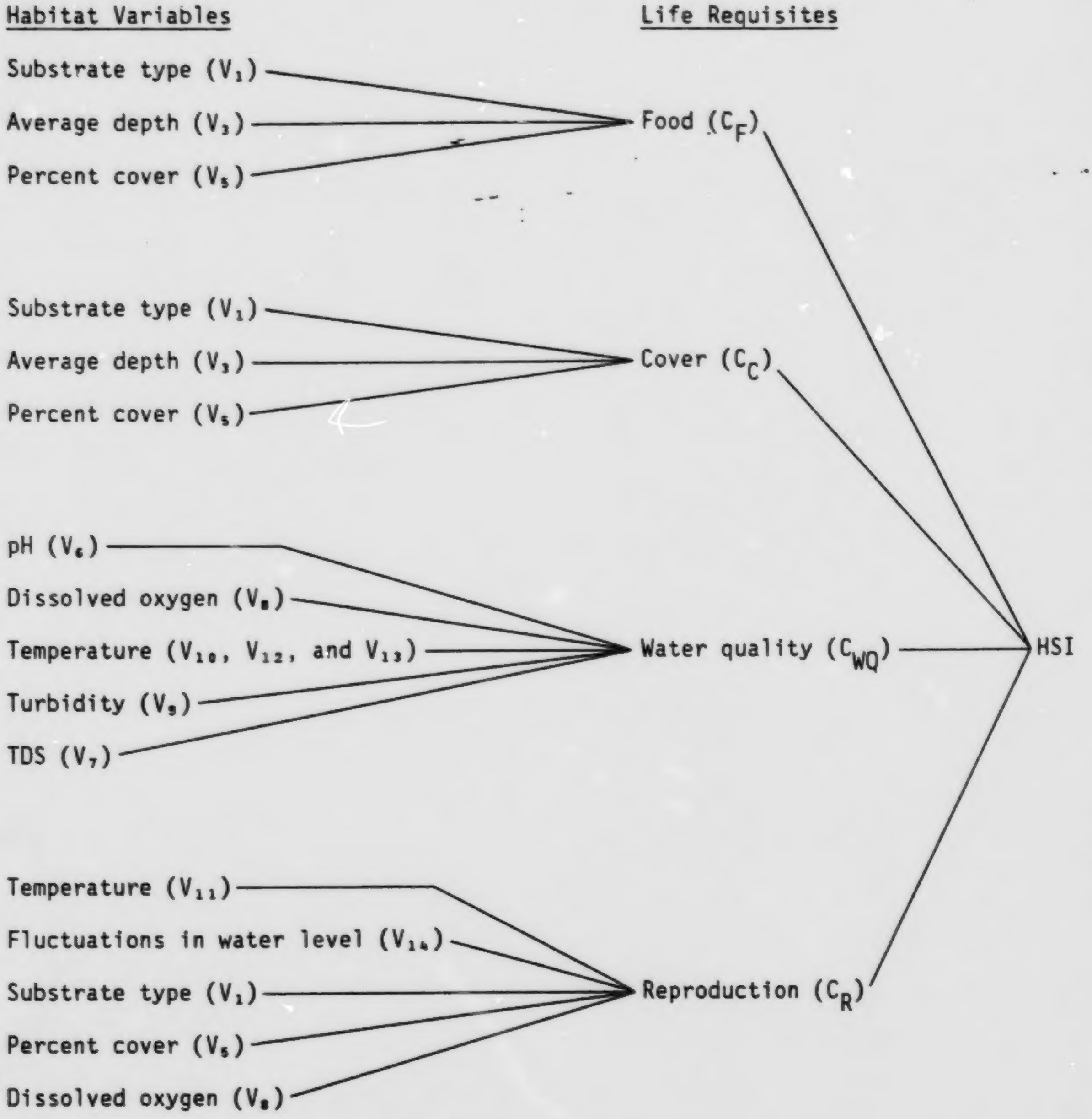

Habitat Variables
Life Requisites
Substrate type (V_1)
Average depth (V_3)
Percent cover (V_5)
Food (C_F)
Substrate type (V_1)
Average depth (V_3)
Percent cover (V_5)
Cover (C_C)
pH (V_6)
Dissolved oxygen (V_8)
Temperature (V_{10}, V_{12}, and V_{13})
Turbidity (V_9)
TDS (V_7)
Water quality (C_{WQ})
HSI
Temperature (V_{11})
Fluctuations in water level (V_{14})
Substrate type (V_1)
Percent cover (V_5)
Dissolved oxygen (V_8)
Reproduction (C_R)

Figure 2. Tree diagram illustrating relationships of habitat variables and life requisites in the lacustrine model for the smallmouth bass.

Cover component. Substrate type (V_1) is important because smallmouth bass prefer a broken rock substrate with crevices and fissures they may use for shelter. Percent pools (V_2) is important because pools are the primary habitat of smallmouth bass. Depth (V_4) of pools affects their quality as cover. Cover is also provided by stumps, trees, boulders, and crevices (V_5).

Water quality component. The water quality component includes pH (V_6), dissolved oxygen (V_8), turbidity (V_9), and temperature (V_{10}, V_{12}, and V_{13}). These parameters affect growth or survival. Interactions with toxic substances are not considered in this model.

Reproduction component. Temperature (V_{11}) is a critical variable in the reproduction component because temperature fluctuations can disrupt spawning. Acute changes in water level (V_{14}) can affect reproductive success. Substrate type (V_1) is important because smallmouth bass only spawn over certain types of substrate. Percent cover (V_5) is included in this component because bass usually nest near some form of cover. Dissolved oxygen level (V_8) is critical for normal embryo development. Excess turbidity (V_9) reduces survivability in streams.

Other component. The other component helps describe habitat suitability for smallmouth bass but contains variables not related to a specific life requisite component. Stream gradient (V_{15}) is included because in riverine environments smallmouth bass usually occur in midorder streams of moderate gradient (but can occur in all stream sizes up to the St. Lawrence River). Gradient is also an important factor related to the formation of pools and riffles.

Model Description - Lacustrine

Food component. Substrate type (V_1) is assumed to be important in terms of food production, because smallmouth bass preference for a rocky substrate appears to be related to production of crayfish and forage fish. Average depth (V_3) is important because smallmouth bass forage in areas of a certain depth. Percent cover (V_5) is included because cover contributes to the production of crayfish and small forage fish.

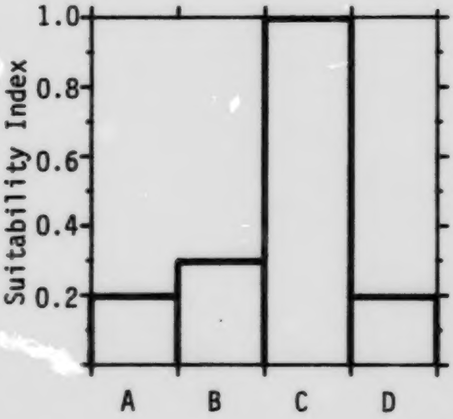
Cover component. Substrate type (V_1) is important because smallmouth bass prefer a broken rock substrate with crevices and fissures they may use for shelter. Depth (V_2) is important because deep, dark, quiet areas are used as cover. Cover in the form of stumps, trees, boulders, and crevices (V_5) is utilized whenever available.

Water quality component. The water quality component includes pH (V_6), dissolved oxygen (V_8), temperature (V_{10}, V_{12}, and V_{13}), and turbidity (V_9). These variables effect growth and survival. Total dissolved solids (TDS) (V_7) is included because smallmouth bass standing crop is correlated with TDS levels.

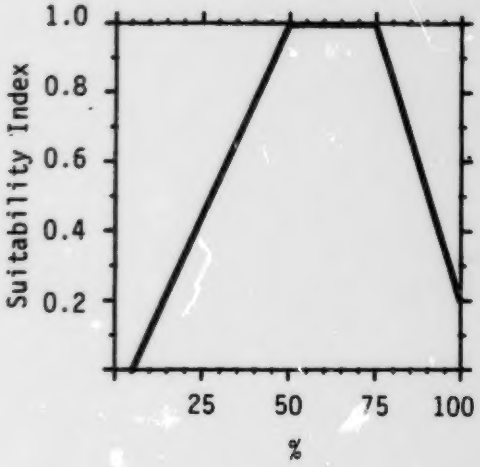
Reproduction component. Temperature (V_{11}) is a critical variable in the reproduction component because temperature fluctuations can disrupt spawning. Fluctuations in water level (V_{14}) can adversely affect reproductive success. Substrate type (V_1) is important because smallmouth bass spawn over a specific type of substrate. Percent cover (V_5) is included because bass usually nest near some form of cover. Dissolved oxygen level (V_8) is critical for normal embryo development.

Suitability Index (SI) Graphs for Model Variables

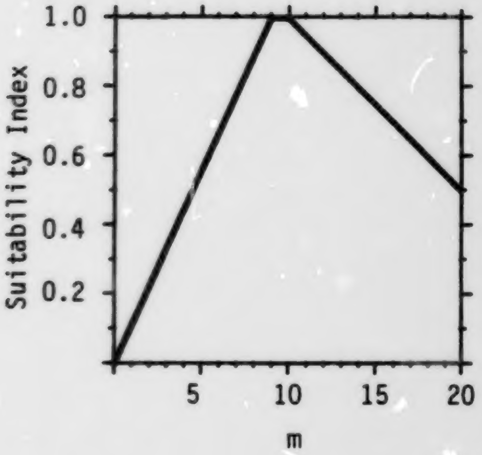
This section contains suitability index graphs for the 15 variables described above and equations for combining the suitability indices for these variable indices into a species HSI using the component approach. Variables may pertain to either a riverine (R) habitat, a lacustrine (L) habitat, or both.

Habitat	Variable		Suitability Graph
R,L	V_1	Dominant substrate type within pool, backwater (R), or shoal area (L). A. Silt and sand (< 0.2 cm) and/or rooted vegetation B. Pebble (0.2-1.5 cm) C. Gravel, broken rock (1.6-2.0 cm), and boulder with adequate interstitial space D. Bedrock	

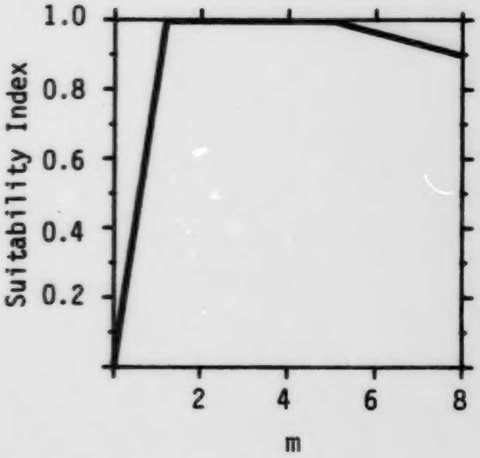
R V_2 Percent pools.



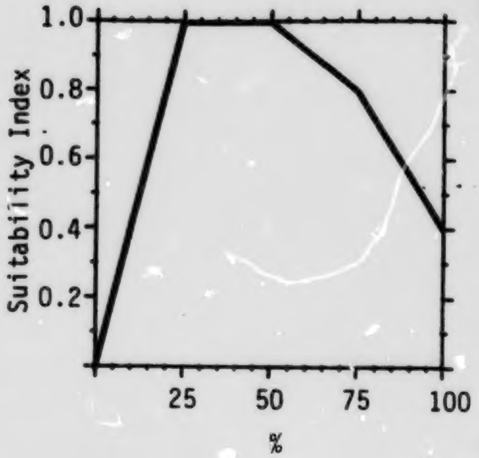
L V_3 Average depth of lake or reservoir during midsummer.



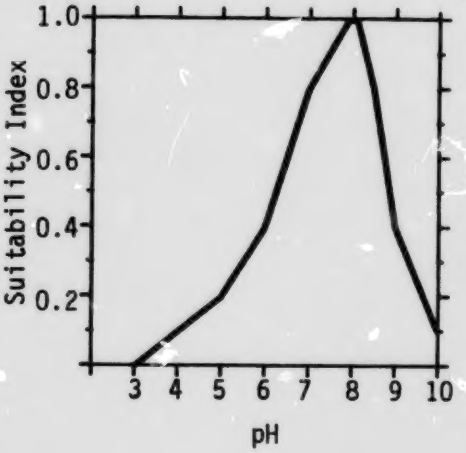
R V_4 Average depth of pools during midsummer.



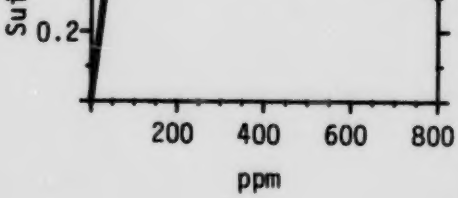
R,L V_5 Percent cover in the form of boulders, stumps, dead trees, and crevices (adults) or vegetation and rocks (fry).

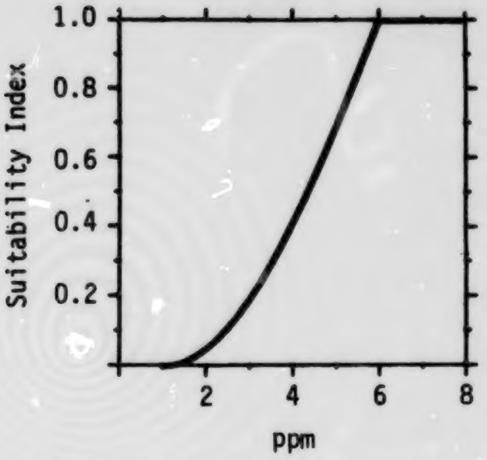
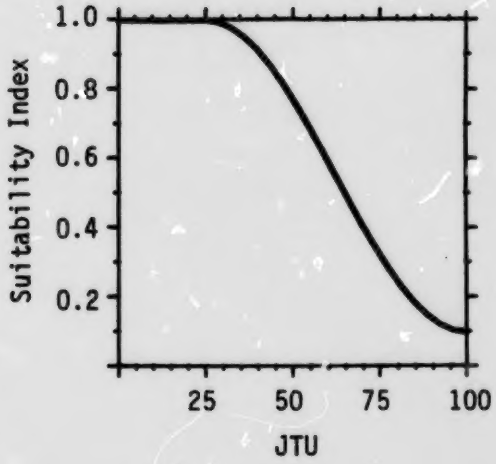
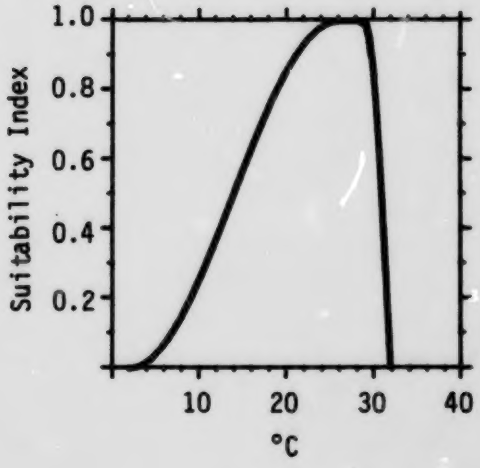


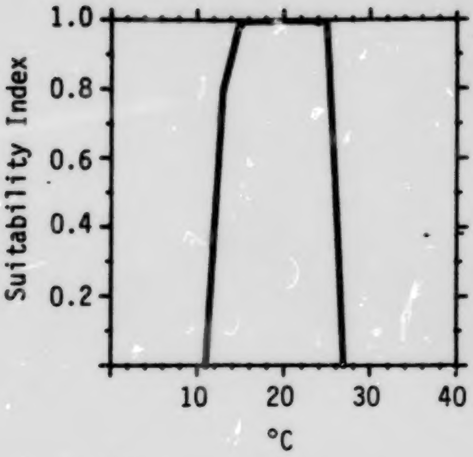
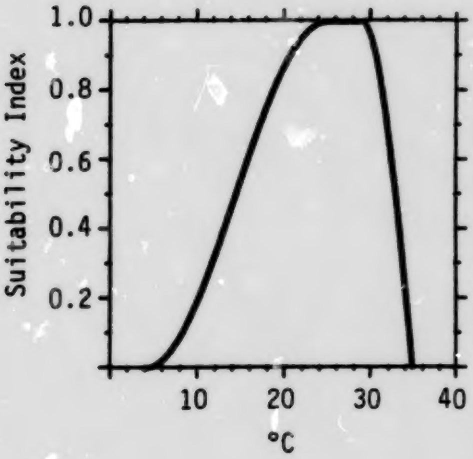
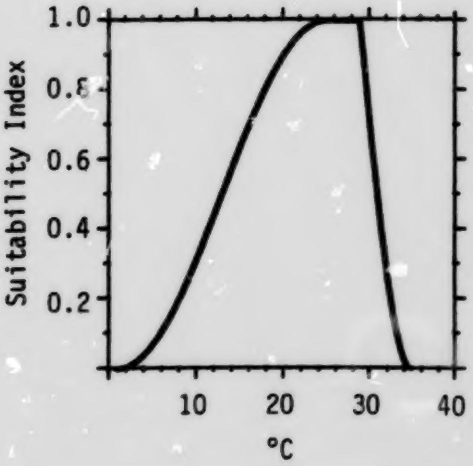
R,L V_6 Average pH level during the year.



L V_7 Average TDS level during the growing season (May to October).

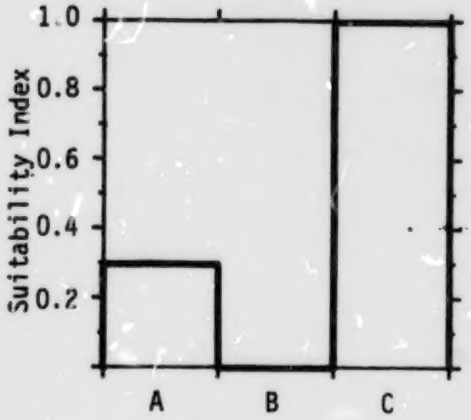


R,L	V_8	Minimum dissolved oxygen level throughout the year.	
R,L	V_9	Maximum monthly average turbidity level during the summer.	
R,L	V_{10}	Water temperature in selected habitat during the growing season (May to October) (adults).	

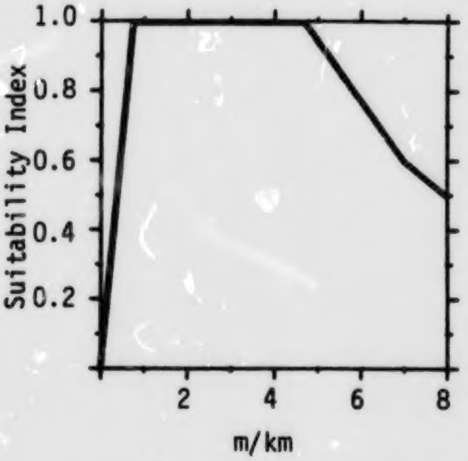
R,L	V_{11}	Water temperature in selected habitat during spawning and for 45 days afterwards (embryo).	
R,L	V_{12}	Water temperature in selected habitat during the growing season (May to October) (fry).	
R,L	V_{13}	Water temperature in selected habitat during the growing season (May to October) (juvenile).	

R,L V_{16} Water level fluctuations during spawning and for 45 days after spawning.

A. Rapid rise during spawning (1-2 m)
B. Rapid fall during spawning or afterwards (.5-1 m)
C. Slow rise previous to spawning (.5-1 m) with stable levels during spawning and afterwards



R V_{15} Stream gradient within representative reach.



Riverine Model

These equations utilize the life requisite approach and consist of five components: food; cover; water quality; reproduction; and other.

Food (C_F).

$$C_F = (V_1 \times V_2 \times V_5)^{1/3}$$

Cover (C_C).

$$C_C = \frac{V_1 + V_2 + V_4 + V_5}{4}$$

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{V_6 + V_8 + V_9 + 2\,[(V_{10} \times V_{12} \times V_{13})^{1/3}]}{5}$$

Except, if V_{10}, V_{12}, or V_{13} is ≤ 0.6, then C_{WQ} equals the lowest of V_{10}, V_{12}, V_{13} or the above equation where the lowest of V_{10}, V_{12}, or V_{13} is substituted for $(V_{10} \times V_{12} \times V_{13})^{1/3}$ in the equation.

Reproduction (C_R).

$$C_R = (V_{11}^2 \times V_{14} \times V_1 \times V_5 \times V_8 \times V_9)^{1/7}$$

Other (C_{OT}).

$$C_{OT} = V_{15}$$

HSI determination

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R \times C_{OT})^{1/5}$$

Or, if C_{WQ} or C_R is ≤ 0.6, the HSI equals the lowest of the following: C_{WQ}; C_R; or the above equation.

Sources of data and assumptions made in developing the suitability indices are presented in Table 1.

Sample data sets using the riverine HSI model are in Table 2.

Lacustrine Model

This model utilizes the life requisite approach and consists of four components: food; cover; water quality; and reproduction.

Food (C_F).

$$C_F = (V_1 \times V_3 \times V_5)^{1/3}$$

Cover (C_C).

$$C_C = \frac{V_1 + V_3 + V_5}{3}$$

Table 1. Data sources for smallmouth bass suitability indices.

	Variable and source	Assumption
V_1	Harrison 1954 Webster 1954 Cleary 1956 Sanderson 1958 Latta 1963 Mraz 1964 Harlan and Speaker 1969 Scott and Crossman 1973 Robbins and MacCrimmon 1974 Coble 1975 Miller 1975 Pflieger 1975 Clancey 1980 Penkal and Gregory 1980	The type of substrate associated with high numbers of smallmouth bass is optimum. The substrate must produce adequate food and be suitable for spawning.
V_2	Trautman 1942 Funk 1957 Sanderson 1958 Brown 1961 Fajen 1962 Keating 1970 Munther 1970 Robbins and MacCrimmon 1974 Coble 1975 Funk and Pflieger 1975 Pflieger 1975 Paragamian 1979 Clancey 1980 Montgomery et al. 1980	Pools have the highest standing crop of smallmouth bass in streams. Conditions must exist for an adequate percentage of pools (vs. riffles) for the habitat to be optimum.
V_3	Turner and MacCrimmon 1970 Coble 1975 Miller 1975 Pflieger 1975	Mean depths associated with large populations of smallmouth bass are optimum.
V_4	Robbins and MacCrimmon 1974 Paragamian 1979 Clancey 1980	Pool depths associated with greater numbers of smallmouth bass are optimum.

Table 1 (continued)

	Variable and source	Assumption
V_5	Coble 1975 Miller 1975 Hubert and Lackey 1980	The strong cover-seeking behavior of smallmouth bass indicates that adequate cover must be present for the habitat to be optimum.
V_6	Butler 1972 Funk and Pflieger 1975 Paragamian 1979	pH levels that contribute to high growth rate and production of smallmouth bass are optimum.
V_7	Jenkins 1975, 1976	TDS levels associated with good production of smallmouth bass are optimum.
V_8	Burdick et al. 1954 Bulkley 1975	Dissolved oxygen levels that ensure the maximum growth rate are optimum.
V_9	Webster 1954 Cleary 1956 Coutant 1975 Hubert and Lackey 1980	Turbidity levels that do not interfere with growth and reproduction are suitable. Levels associated with high numbers of smallmouth bass are optimum.
V_{10}	Doan 1940 Webster 1954 Ferguson 1958 Brown 1961 Bennett 1965 Munther 1970 Forney 1972 Barans and Tubb 1973 Robbins and MacCrimmon 1974 Cherry et al. 1975 Coble 1975 Coutant 1975 Clancey 1980 Shuter et al. 1980 Wren 1980 Mathur et al. 1981	Temperatures that result in maximum growth rates are optimum. Temperatures that result in slow growth have low suitability. Lethal temperatures are unsuitable.

Table 1 (concluded)

	Variable and source	Assumption
V_{11}	Webster 1954 Henderson and Foster 1957 Watt 1959 Latta 1963 Harlan and Speaker 1969 Turner and MacCrimmon 1970 Scott and Crossman 1973 Coble 1975 Montgomery et al. 1980 Shuter et al. 1980	Optimum temperatures for embryos are where spawning or male nest guarding is not disrupted, and development is normal.
V_{12}	Webster 1954 Keast 1968 Larimore and Duever 1968 Munther 1970 Coble 1975 Coutant 1975 Pflieger 1975 Oliver et al. 1979 Shuter et al. 1980	Abundant numbers of fry are found in areas with the optimum temperature. Maximum growth occurs at optimum temperatures. Temperatures that slow growth and activity have lower suitability. Lethal temperatures are unsuitable.
V_{13}	Reynolds 1965 Munther 1970 Barans and Tubb 1973 Horning and Pearson 1973 Cherry et al. 1975 Coutant 1975 Shuter et al. 1980 Wrenn 1980	Temperatures that promote high growth rates are optimum. Temperatures where growth and activity slows are suboptimum, and lethal temperatures are unsuitable.
V_{14}	Watson 1955 Neves 1975 Pflieger 1975 Montgomery et al. 1980	Rising water conditions associated with successful spawning are optimum. Fluctuating conditions associated with nest desertion, no embryo development, and lower reproductive success are unsuitable.
V_{15}	Trautman 1942 Hallam 1959 Robbins and MacCrimmon 1974 Coble 1975 Funk and Pflieger 1975	Stream gradients associated with the largest populations of smallmouth bass are optimum.

Table 2. Sample data sets using riverine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Substrate type	V_1	gravel, cobble	1.0	pebble	0.3	gravel, cobble	1.0
% pools	V_2	40	0.8	85	0.6	50	1.0
Average depth (m)	V_4	2	1.0	8	0.9	4	1.0
% cover	V_5	80	0.7	80	0.7	50	1.0
pH	V_6	7	0.8	9	0.4	8	1.0
Dissolved oxygen (ppm)	V_8	6	1.0	4	0.4	8	1.0
Turbidity (JTU)	V_9	45	0.8	60	0.6	10	1.0
Temperature (° C) (adult)	V_{10}	22	0.9	30	0.8	28	1.0
Temperature (° C) (embryo)	V_{11}	15	1.0	12	0.6	20	1.0
Temperature (° C) (fry)	V_{12}	19	0.8	13	0.4	24	1.0
Temperature (° C) (juvenile)	V_{13}	16	0.7	11	0.4	28	1.0
Water level fluctuations (m)	V_{14}	slow rise	1.0	rapid rise	0.3	slow rise	1.0
Gradient (m/km)	V_{15}	2	1.0	0.5	0.6	3	1.0

Table 2 (concluded)

Variable	Data set 1 Data	 SI	Data set 2 Data	 SI	Data set 3 Data	 SI
Component SI						
C_F =		0.82		0.50		1.00
C_C =		0.88		0.63		1.00
C_{WQ} =		0.84		0.40		1.00
C_R =		0.92		0.47		1.00
C_{OT} =		1.00		0.60		1.00
HSI =		0.89		0.40		1.00

Water Quality (C_{WQ}).

$$C_{WQ} = \frac{V_6 + V_7 + V_8 + V_9 + 2[(V_{10} \times V_{12} \times V_{13})^{1/3}]}{6}$$

Except, if V_{10}, V_{12}, or V_{13} is ≤ 0.6, C_{WQ} equals the lowest of V_{10}, V_{12}, or V_{13} or the above equation where the lowest of V_{10}, V_{12}, or V_{13} is substituted for $(V_{10} \times V_{12} \times V_{13})^{1/3}$ in the equation.

Reproduction (C_R)

$$C_R = (V_{11}^2 \times V_{14} \times V_1 \times V_5 \times V_8)^{1/6}$$

HSI determination.

$$HSI = (C_F \times C_C \times C_{WQ} \times C_R)^{1/4}$$

Or, if C_{WQ} or C_R is ≤ 0.6, the HSI equals the lowest of the following: C_{WQ}; C_R; or the above equation.

Sample data sets using the lacustrine HSI model are in Table 3.

Table 3. Sample data sets using lacustrine HSI model.

Variable		Data set 1		Data set 2		Data set 3	
		Data	SI	Data	SI	Data	SI
Substrate	V_1	gravel, cobble	1.0	pebble	0.3	gravel, cobble	1.0
Depth (m)	V_3	7	0.8	5	0.5	10	1.0
% cover	V_5	80	0.7	80	0.7	50	1.0
pH	V_6	7	0.8	9	0.4	8	1.0
TDS (ppm)	V_7	200	1.0	600	0.6	200	1.0
Dissolved oxygen (ppm)	V_8	6	1.0	4	0.4	8	1.0
Turbidity (JTU)	V_9	45	0.8	60	0.6	10	1.0
Temperature (° C) (adult)	V_{10}	22	0.9	30	0.8	28	1.0
Temperature (° C) (embryo)	V_{11}	15	1.0	12	0.6	20	1.0
Temperature (° C) (fry)	V_{12}	19	0.8	13	0.4	24	1.0
Temperature (° C) (juvenile)	V_{13}	16	0.7	11	0.4	28	1.0
Water level fluctuations (m)	V_{14}	slow rise	1.0	rapid rise	0.3	slow rise	1.0
Component SI							
C_F =			0.82		0.47		1.0
C_C =			0.83		0.50		1.0
C_{WQ} =			0.87		0.47		1.0
C_R =			0.94		0.67		1.0
HSI =			0.86		0.47		1.0

FWS/OBS-82/10.60
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HABITAT SUITABILITY INFORMATION: RAINBOW TROUT

by

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PREFACE

The Habitat Suitability Index (HSI) models presented in this publication aid in identifying important habitat variables. Facts, ideas, and concepts obtained from the research literature and expert reviews are synthesized and presented in a format that can be used for impact assessment. The models are hypotheses of species-habitat relationships, and model users should recognize that the degree of veracity of the HSI model, SI graphs, and assumptions will vary according to geographical area and the extent of the data base for individual variables. After clear study objectives have been set, the HSI model building techniques presented in U.S. Fish and Wildlife Service (1981)[1] and the general guidelines for modifying HSI models and estimating model variables presented in Terrell et al. (1982)[2] may be useful for simplifying and applying the models to specific impact assessment problems. Simplified models should be tested with independent data sets if possible.

A brief discussion of the appropriateness of using selected Suitability Index (SI) curves from HSI models as a component of the Instream Flow Incremental Methodology (IFIM) is provided. Additional SI curves, developed specifically for analysis of rainbow trout habitat with IFIM, also are presented.

The U.S. Fish and Wildlife Service encourages model users to provide comments, suggestions, and test results that may help us increase the utility and effectiveness of this habitat-based approach to impact assessment. Please send comments to:

Habitat Evaluation Procedures Group or
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Ft. Collins, CO 80526-2899

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[1] U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. n.p.

[2] Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Fish Wildl. Serv. FWS/OBS-82/10.A. 54 pp.

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RAINBOW TROUT (Salmo gairdneri)

HABITAT USE INFORMATION

General

Because of variations in their life history pattern and the habitat in which they spend the majority of their adult lives, rainbow trout (Salmo gairdneri) can be subdivided into three basic ecological forms: (1) anadromous steelhead trout; (2) resident stream rainbow trout; and (3) lake or reservoir dwelling rainbow trout. It is important to recognize that there is a genetic or hereditary basis for each ecological form. For example, a "lake or reservoir" rainbow may react very differently to environmental stimuli associated with survival, feeding, and growth if it belongs to a population that has been evolving and adapting to the particular lake for hundreds or thousands of years, when compared to hatchery rainbow trout that have just been released in the lake.

Nonanadromous rainbow trout are native to the Pacific Coast drainages inland as far as the Rockies and from the Rio del Presidio River in Mexico to the Kuskokwim River in Southwestern Alaska (Behnke 1979). They are also native to the Peace River drainage of British Columbia and the headwaters of the Athabaska River (of the McKenzie River basin) in Alberta (MacCrimmon 1971). Their present range extends from the Arctic Circle to 55° S latitude. They are perhaps the most widely introduced fish species; the only continent lacking rainbow trout is Antarctica (McAfee 1966; MacCrimmon 1971). Rainbow trout occur from 0 to 4,500 m above sea level (MacCrimmon 1971).

Anadromous steelhead trout are distributed along the Pacific coast from the Santa Ynez Mountains, California, to the Alaska Peninsula (Jordan and Evermann 1902; Withler 1966). Large rainbow trout on and north of the Alaska Peninsula appear to be nonanadromous.

Age, Growth, and Food

Female rainbow trout typically become sexually mature during their third year; males become sexually mature during their second or third year (Holton 1953; Lagler 1956; McAfee 1966). Life expectancy averages 3 to 5 years in most southern lake populations, but life expectancy of steelhead and northern lake populations appears to be 4 to 8 years. Maximum size also varies with population, area, and habitat. Steelhead may grow to 122 cm long and weigh 16 kg. The average angler's catch is 3.6 to 4 kg. Great Lakes rainbow grow to 244 cm, but seldom exceed 9 kg (Scott and Crossman 1973). Size in wild rainbow trout appears to be a function of longevity, delayed age at maturity, and length of ocean residence for steelhead.

Adult and juvenile rainbow trout are basically opportunistic feeders and consume a wide variety of foods. Availability of different foods depends on many factors, including water type, season, and size of the trout (McAfee 1966). The diet of rainbow trout consists mainly of aquatic insects (Allen 1969; Carlander 1969; Baxter and Simon 1970; Scott and Crossman 1973), although foods, such as zooplankton (McAfee 1966), terrestrial insects, and fish (Carlander 1969), are locally or seasonally important. The relative importance of aquatic and terrestrial insects to resident stream rainbow trout varies greatly among different environments, seasonally and dielly, and with the age of the trout (Bisson 1978). Forty to fifty percent or more of the summer food of trout in headwater streams may be composed of terrestrial insects (Hunt 1971). Adult stream rainbow trout occasionally consume significant quantities of vegetation, mostly algae (McAfee 1966). Stream trout have no mechanism to break down cell walls in vegetation and cannot obtain nutrients from it, therefore, vegetation is thought to be consumed because of the invertebrates attached to it (Behnke pers. comm.). Bottom fauna may comprise 83 to 94% of the winter diet of adult and juvenile lake rainbow trout (Crossman and Larkin 1959). Lake trout usually reach 30 cm in length before they actively prey on other fish species (Crossman 1959; Crossman and Larkin 1959; Johannes and Larkin 1961).

Reproduction

Rainbow trout spawn almost exclusively in streams. Some rainbow and rainbow-cutthroat trout hybrids have successfully reproduced in lakes without tributary streams (Behnke, pers. comm.). Spawning in certain river systems may occur in intermittent tributary streams (Everest 1973; Price and Geary 1979). In one case, up to 47% of the stream rainbow trout population spawned in intermittent tributaries that dried up in midsummer and fall (Erman and Leidy 1975; Erman and Hawthorne 1976). Spawning normally occurs from January to July, depending on location. Hatchery selection has resulted in fall spawning strains, and spawning of hatchery fish may occur in almost any month of the year, depending on the strain (Behnke 1979). A few populations outside of the native range have modified their spawning times to avoid adverse environmental conditions (Van Velson 1974; Kaya 1977). Viable eggs have resulted from December and January spawning at water temperatures of 0.3 to 2.0° C in a tributary of Lake Huron (Dodge and MacCrimmon 1970). However, eggs exposed to long periods of 0 to 4° C temperatures suffered high mortality and abnormalities.

The female generally selects a redd site in gravel substrate at the head of a riffle or downstream edge of a pool (Greeley 1932; Orcutt et al. 1968). The redd pit, constructed primarily by the female, is typically longer than the female and deeper than her greatest body depth (Greeley 1932). Average depth of egg deposition is 15 cm (Hooper 1973).

Rainbow trout residing in lakes and reservoirs have a similar life history pattern to the steelhead trout, but generally lack a physiological smolt stage. Juveniles migrate from natal streams to a freshwater lake rearing area, instead of to the ocean. Lake rainbow trout most commonly spend two summers in a stream and two summers in a lake before maturing (Greeley 1933). Spawning takes place during the growing season in an inlet or an outlet stream, with more than 90% of the trout returning to the stream of natal origin (Greeley 1933; Lindsey et al. 1959). Lakes with no inlet or outlet streams generally do not possess a reproducing population of rainbow trout. Whether spawning adults enter through an inlet or an outlet, they and their progeny will return to the lake (Lindsey et al. 1959). These movements from natal sites to lake rearing areas appear to be directed by genetic/environmental interactions (Raleigh 1971).

Spawning usually begins one month earlier in the outlet than in the inlet (Lindsey et al. 1959; Hartman et al. 1962); the difference in time is apparently related to temperature differences (Lindsey et al. 1959). In Bothwell Creek, a tributary of Lake Huron, 65% of the spawning run were repeat spawners (Dodge and MacCrimmon 1970). The typical survival rate of repeat spawners is 10-30%, with extremes from 1% to more than 65%.

Average fecundity of rainbow trout is related to length, but is highly variable, ranging from 500 to 3,161 eggs per stream resident female (Carlander 1969). Fecundity of lake resident females ranges from 935 to 4,578 eggs per female, with an average of 2,028 eggs per female (Mann 1969).

Anadromy

Anadromous steelhead spawn in freshwater streams. Steelhead smolt and migrate in late spring (Wagner 1968; Chrisp and Bjornn 1978). Photoperiod appears to be the dominant triggering mechanism for parr-smolt transformation, with temperature affecting the rate of transformation (Wagner 1974). Smolts that have not migrated by approximately the summer solstice revert to parr and attempt to migrate the following season (Zaugg and Wagner 1973). Juveniles reside in freshwater for 1 to 4 years before migrating to the sea as smolts. They mature after 1 to 4 years of ocean residence and return to freshwater rivers to spawn (Chapman 1958; Withler 1966). A large number of the steelhead adults die after spawning, but some (3 to 53%) return to the ocean and spawn again (Bjornn 1960; Withler 1966; Fulton 1970). Steelhead spawners tend to be larger and older in the northern portion of their range (Withler 1966).

There are both winter and summer-run steelhead. Summer-run adults enter freshwater rivers in the spring and early summer. Winter-run steelhead enter freshwater rivers in the fall and winter. As many as 98.8% of the trout return to their natal stream (McAfee 1966). Both groups typically spawn in the spring and early summer months, March through early July (Withler 1966; Orcutt et al. 1968), although spawning at other times of the year has been reported. Summer-run and winter-run steelhead are distinguished by differences in behavior prior to spawning and, to a limited extent, by appearance (Withler 1966).

When fish migrate from freshwater to saltwater, they are moving from a hypotonic medium to a hypertonic medium. Gill Na-K ATPase activity appears to be related to saltwater tolerance and smolting (Conte and Wagner 1965; Zaugg and Wagner 1973; Adams et al. 1975). Water temperature affects Na-K-related ATPase activity. Juvenile steelhead kept in water warmer than 13° C from March to June experienced reduced levels of smoltification and very low levels of ATPase activity (Zaugg and McLain 1972; Zaugg and Wagner 1973; Wagner 1974). Water temperatures of 10.5 to 13° C resulted in a moderate ATPase response, and temperatures of 6.5 to 10° C resulted in the highest activity levels for the longest period of time (Adams et al. 1975). The effect of temperature on ATPase activity is reversible within a season (Zaugg and McLain 1972).

Coefficient of condition is another indicator of parr-smolt transformation. Juvenile steelhead not undergoing a smolt transformation do not lose weight; whereas, steelhead undergoing transformation lose enough weight to result in a greatly reduced coefficient of condition (Adams et al. 1973; Wagner 1974).

A fork length (i.e., anterior most extremity to the notch in the tail fin of fork-tailed fish or to the center of the tail fin when the tail is not forked) of 160 mm is the average length juvenile parr must reach before they undergo the physiological and morphological changes of smolting (Fessler and Wagner 1969; Chrisp and Bjornn 1978). Hatchery-reared steelhead typically reach critical size in one growing season, but native stream steelhead usually require two or more growing seasons (Chrisp and Bjornn 1978). Migrating smolts at the lower end of the minimum length requirement stay in the ocean longer than smolts that are larger in size when they migrate (Chapman 1958).

The freshwater habitat requirements of adult and juvenile steelhead are assumed to be essentially the same as those for other rainbow trout. Exceptions for steelhead are: (1) low temperature (< 13° C) requirements during the spring months for smoltification of juveniles; and (2) the presence of moderate temperatures (preferably ≤ 20° C) and freshets (periodic high flows) during the upstream migration of adults.

Specific Habitat Requirements

Optimal rainbow trout riverine habitat is characterized by clear, cold water; a silt-free rocky substrate in riffle-run areas; an approximately 1:1 pool-to-riffle ratio, with areas of slow, deep water; well-vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks (Raleigh and Duff 1980).

Optimal lacustrine habitat is characterized by clear, cold, deep lakes that are typically oligotrophic, but may vary in size and chemical quality, particularly in reservoir habitats. Rainbow trout are primarily stream spawners and generally require tributary streams with gravel substrate in riffle areas for reproduction to occur.

Trout production is typically greatest in streams with a pool-to-riffle ratio of approximately 1:1 (Fortune and Thompson 1969; Thompson and Fortune 1970). Pools are inhabited throughout the year by adult and juvenile stream rainbow trout. Pools are important to trout as a refuge from adverse conditions during the winter. Because pools differ in their ability to provide resting areas and cover, this model subdivides pools into three classes. Lewis (1969) found that streams with deep, low velocity pools containing extensive cover had the most stable trout populations.

Available trout literature does not often clearly distinguish between feeding stations, escape cover, and winter cover requirements. Prime requisites for optimal feeding stations appear to be low water velocity and access to a plentiful food supply; i.e., energy accretion at a low energy cost. Water depth is not clearly defined as a selection factor, and overhead cover is preferred but not essential. Escape cover, however, must be nearby. The feeding stations of dominant adult trout include overhead cover when available. The feeding stations of subdominant adults and juveniles, however, do not always include overhead cover. Antagonistic behavior occurs at feeding stations and hierarchies are established, but escape cover is often shared.

Cover is recognized as one of the essential components of trout streams. Boussu (1954) was able to increase the number and weight of trout in stream sections by adding artificial brush cover and to decrease numbers and weight of trout by removing brush cover and undercut banks. Lewis (1969) reported that the amount of cover was important in determining the number of trout in sections of a Montana stream. Stewart (1970) found that mean depth and underwater, overhanging bank cover were the most important variables in determining the density of brook and rainbow trout longer than 18 cm in a northcentral Colorado stream. Cover for adult trout consists of areas of obscured stream bottom in water ≥ 15 cm deep with a velocity of ≤ 15 cm/sec (Wesche 1980). Wesche (1980) reported that, in larger streams, the abundance of trout ≥ 15 cm in length increased with water depth; most trout were at depths of at least 15 cm. Cover is provided by overhanging vegetation; submerged vegetation; undercut banks; instream objects, such as debris piles, logs, and large rocks; pool depth; and surface turbulence (Giger 1973). A cover area of ≥ 25% of the total stream area provides adequate cover for adult trout; a cover area of ≥ 15% is adequate for juveniles. The main uses of summer cover are probably predator avoidance and resting.

In some streams, the major factor limiting salmonid densities may be the amount of adequate overwintering habitat, rather than the amount of summer rearing habitat (Bustard and Narver 1975a). Winter hiding behavior in salmonids is triggered by low temperatures (Chapman and Bjornn 1969; Everest 1969; Bustard and Narver 1975a,b). Cutthroat trout were found under boulders, log jams, upturned roots, and debris when temperatures neared 4 to 8° C, depending on the water velocity (Bustard and Narver 1975a). Everest (1969) found juvenile rainbow trout 15 to 30 cm deep in the substrate, which was often covered by 5 to 10 cm of anchor ice. Lewis (1969) reported that, during winter, adult rainbow trout tended to move into deeper water (first class pools). Bjornn (1971) indicated that downstream movement during or preceding winter did not occur if sufficient winter cover was available locally. Trout move to winter cover to avoid physical damage from ice scouring (Hartman 1965; Chapman and Bjornn 1969) and to conserve energy (Chapman and Bjornn 1969; Everest 1969).

Headwater trout streams are relatively unproductive. Most energy inputs to the stream are in the form of allochthonous materials, such as terrestrial vegetation and terrestrial insects (Idyll 1942; Chapman 1966; Hunt 1971). Aquatic invertebrates are most abundant and diverse in riffle areas with rubble substrate and on submerged aquatic vegetation (Hynes 1970). However, optimal substrate for maintenance of a diverse invertebrate population consists of a mosaic of mud, gravel, rubble, and boulders, with rubble dominant. A pool-to-riffle ratio of about 1:1 (approximately a 40 to 60% pool area) appears to provide an optimal mix of food producing and rearing areas for trout (Needham 1940). In riffle areas, the presence of fines (> 10%) reduces the production of invertebrate fauna (based on Cordone and Kelly 1961; Crouse et al. 1981).

Canopy cover is important in maintaining shade for stream temperature control and in providing allochthonous materials to the stream. Too much shade, however, can restrict primary productivity in a stream. Stream temperatures can be increased or decreased by controlling the amount of shade. About 50 to 75% midday shade appears optimal for most small trout streams (adapted from Oregon/Washington Interagency Wildlife Conference 1979). Shading becomes less important as stream gradient and size increase. In addition, a well vegetated riparian area helps control watershed erosion. In most cases, a buffer strip about 30 m wide, 80% of which is either well vegetated or has stable rocky stream banks, provides adequate erosion control and maintains undercut stream banks characteristic of good trout habitat. The presence of fines in riffle-run areas can adversely affect embryo survival, food production, and cover for juveniles.

There is a definite relationship between the annual flow regime and the quality of trout habitat. The most critical period is typically during base flow (lowest flows of late summer to winter). A base flow ≥ 50% of the average annual daily flow is considered excellent for maintaining quality trout habitat, a base flow of 25 to 50% is considered fair, and a base flow of < 25% is considered poor (adapted from Binns and Eiserman 1979; Wesche 1980).

Adult. Dissolved oxygen requirements vary with species, age, prior acclimation temperature, water velocity, activity level, and concentration of substances in the water (McKee and Wolf 1963). As temperature increases, the dissolved oxygen saturation level in the water decreases, while the dissolved oxygen requirement for the fish increases. As a result, an increase in temperature resulting in a decrease in dissolved oxygen can be detrimental to the fish. Optimal oxygen levels for rainbow trout are not well documented, but appear to be ≥ 7 mg/l at temperatures ≤ 15° C and ≥ 9 mg/l at temperatures > 15° C. Doudoroff and Shumway (1970) demonstrated that swimming speed and growth rates for salmonids declined with decreasing dissolved oxygen levels. In the summer (≥ 10° C), cutthroat trout generally avoid water with dissolved oxygen levels of less than 5 mg/l (Trojnar 1972; Sekulich 1974).

The incipient lethal level of dissolved oxygen for adult and juvenile rainbow trout is approximately 3 mg/l or less, depending on environmental conditions, especially temperature (Gutsell 1929; Burdick et al. 1954; Alabaster et al. 1957; Downing and Merken 1957; Doudoroff and Warren 1962). Although fish can survive at concentrations just above this level, they must make various physiological adaptations to low levels of dissolved oxygen that may jeopardize their health (Randall and Smith 1967; Kutty 1968; Hughes and Saunders 1970; Cameron 1971; Holeton 1971). For example, low levels of dissolved oxygen can result in reduced fecundity and even prevent spawning. Large fluctuations in dissolved oxygen may cause a reduction in food consumption and impaired growth (Doudoroff and Shumway 1970).

The upper and lower incipient lethal temperatures for adult rainbow are 25° and 0° C, respectively (Black 1953; Lagler 1956; McAfee 1966; Bidgood and Berst 1969; Hokanson et al. 1977). Zero growth rate occurred at 23° C for rainbow trout in the laboratory (Hokanson et al. 1977). Changes in the natural growth rate of rainbow trout are detrimental to their development and survival. Therefore, 25° C should be considered the upper limit suitable for rainbow trout and then only for short periods of time. Adult lake rainbow trout select waters with temperatures between 7 to 18° C (Fast 1973; May 1973) and avoid permanent residence where temperatures are above 18° C (May 1973). Adult stream rainbow trout select temperatures between 12.0 and 19.3° C (Garside and Tait 1958; Bell 1973; Cherry et al. 1977; McCauley et al. 1977). Dickson and Kramer (1971) reported that the greatest scope of rainbow trout activity occurred at 15 and 20° C when tested at 5° C temperature intervals. Stream rainbow trout select temperatures between 12 and 19° C; lake resident trout avoid temperatures > 18° C. Therefore, the optimal temperature range for rainbow trout is assumed to be 12 to 18° C.

The depth distribution of adult lake rainbow trout is usually a function of dissolved oxygen, temperature, and food. Adult lake rainbow trout remain at depths ≤ the 18° C isotherm and at dissolved oxygen levels > 3 mg/l (May 1973; Hess 1974).

Focal point velocities for adult cutthroat trout at territorial stations in Idaho streams were primarily between 10 and 14 cm/sec, with a maximum of 22 cm/sec (Griffith 1972). The focal point velocities for adult rainbow trout are assumed to be similar.

Precise pH tolerance and optimal ranges are not well documented for rainbow trout. Most trout populations can probably tolerate a pH range of 5.5 to 9.0, with an optimal range of 6.5 to 8.0 (Hartman and Gill 1968; Behnke and Zarn 1976).

Withler (1966) suggested that the correlation between the winter steelhead run and increased water volume indicates that a freshet condition is required to initiate upstream movement of spawners. Everest (1973) stated that speed of migration of summer-run steelhead in the Rogue River was inversely related to temperature and directly related to streamflows. Hanel (1971) observed that steelhead migration into the Iron Gate fish hatchery ceased when the water temperature dropped to 4° C and did not resume for several weeks until the temperature increased. This suggests that water temperatures should be > 4° C but ≤ 18° C, and streamflow conditions should be above normal seasonal flows during upstream migrations of steelhead adults.

Embryo. Incubation time varies inversely with temperature. Eggs usually hatch within 28 to 40 days (Cope 1957), but may take as long as 49 days (Scott and Crossman 1973). The optimal temperature for embryo incubation is about 7 to 12° C. Calhoun (1966) reported increased mortalities of rainbow embryos at temperatures < 7° C and normal development at temperatures ≥ 7 but ≤ 12° C. The optimal water velocity above rainbow trout redds is between 30 and 70 cm/sec. Velocities less than 10 cm/sec or greater than 90 cm/sec are unsuitable (Delisle and Eliason 1961; Thompson 1972; Hooper 1973).

The combined effects of temperature, dissolved oxygen, water velocity, and gravel permeability are important for successful incubation (Coble 1961). In a 30% sand and 70% gravel mixture, only 28% of implanted steelhead embryos hatched; of the 28% that hatched, only 74% emerged (Bjornn 1969; Phillips et al. 1975). Optimal spawning gravel conditions are assumed to include ≤ 5% fines; ≥ 30% fines are assumed to result in low survival of embryos and emerging yolk-sac fry. Suitable incubation substrate is gravel that is 0.3 to 10.0 cm in diameter (Delisle and Eliason 1961; Orcutt et al. 1968; Hooper 1973; Duff 1980). Optimal substrate size depends on the size of the spawners, but is assumed to average 1.5 to 6.0 cm in diameter for rainbows < 50 cm long and 1.5 to 10.0 cm in diameter for spawners ≥ 50 cm long (Orcutt et al. 1968). Doudoroff and Shumway (1970) reported that salmonids that incubated at low dissolved oxygen levels were weak and small with slower development and more abnormalities. Dissolved oxygen requirements for rainbow trout embryos are not well documented, but are assumed to be similar to the requirements for adults.

Fry. Rainbow trout remain in the gravel for about 2 weeks after hatching (Scott and Crossman 1973) and emerge 45 to 75 days after egg fertilization, depending on water temperature (Calhoun 1944; Lea 1968). When moving from natal gravels to rearing areas, rainbow trout fry exhibit what appears to be three distinct genetically controlled movement patterns: (1) movement downstream to a larger river, lake, or to the ocean; (2) movement upstream from an outlet river to a lake; or (3) local dispersion within a common spawning and rearing area to areas of low velocity and cover (Raleigh and Chapman 1971). Fry of lake resident fish may either move into the lake from natal streams during the first growing season or overwinter in the spawning stream and move into the lake during subsequent growing seasons.

Fry residing in streams prefer shallower water and slower velocities than do other life stages of stream trout (Miller 1957; Horner and Bjornn 1976). Fry utilize velocities less than 30 cm/sec, but velocities less than 8 cm/sec are preferred (Griffith 1972; Horner and Bjornn 1976). Fry survival decreases with increased velocity after the optimal velocity has been reached (Bulkley and Benson 1962; Drummond and McKinney 1965). A pool area of 40% to 60% of the total stream area is assumed to provide optimal fry habitat. Cover in the form of aquatic vegetation, debris piles, and the interstices between rocks is critical. Griffith (1972) states that younger trout live in shallower water and stay closer to escape cover than do older trout. Few fry are found more than 1 m from cover. As the young trout grow, they move to deeper, faster water. Everest (1969) suggested that one reason for this movement was the need for cover, which is provided by increased water depth, surface turbulence, and substrate that consists of large material.

Stream resident trout fry usually overwinter in shallow areas of low velocity near the stream margin, with rubble being the principal cover (Bustard and Narver 1975a). Optimal size of substrate used as winter cover by rainbow fry and small juveniles ranges from 10 to 40 cm in diameter (Hartman 1965; Everest 1969). An area of substrate of this size class that is ≥ 10% of the total habitat probably provides adequate cover for rainbow fry and small juveniles. The use of small diameter rocks (gravel) for winter cover may result in increased mortality due to greater shifting of the substrate (Bustard and Narver 1975a). The presence of fines (≥ 10%) in the riffle-run areas reduces the value of the area as cover for fry and small juveniles. Mantelman (1958) reported a preferred temperature range of 13 to 19° C for fry. Because fry occupy habitats contiguous with adults, their temperature and oxygen requirements are assumed to be similar to those of adults.

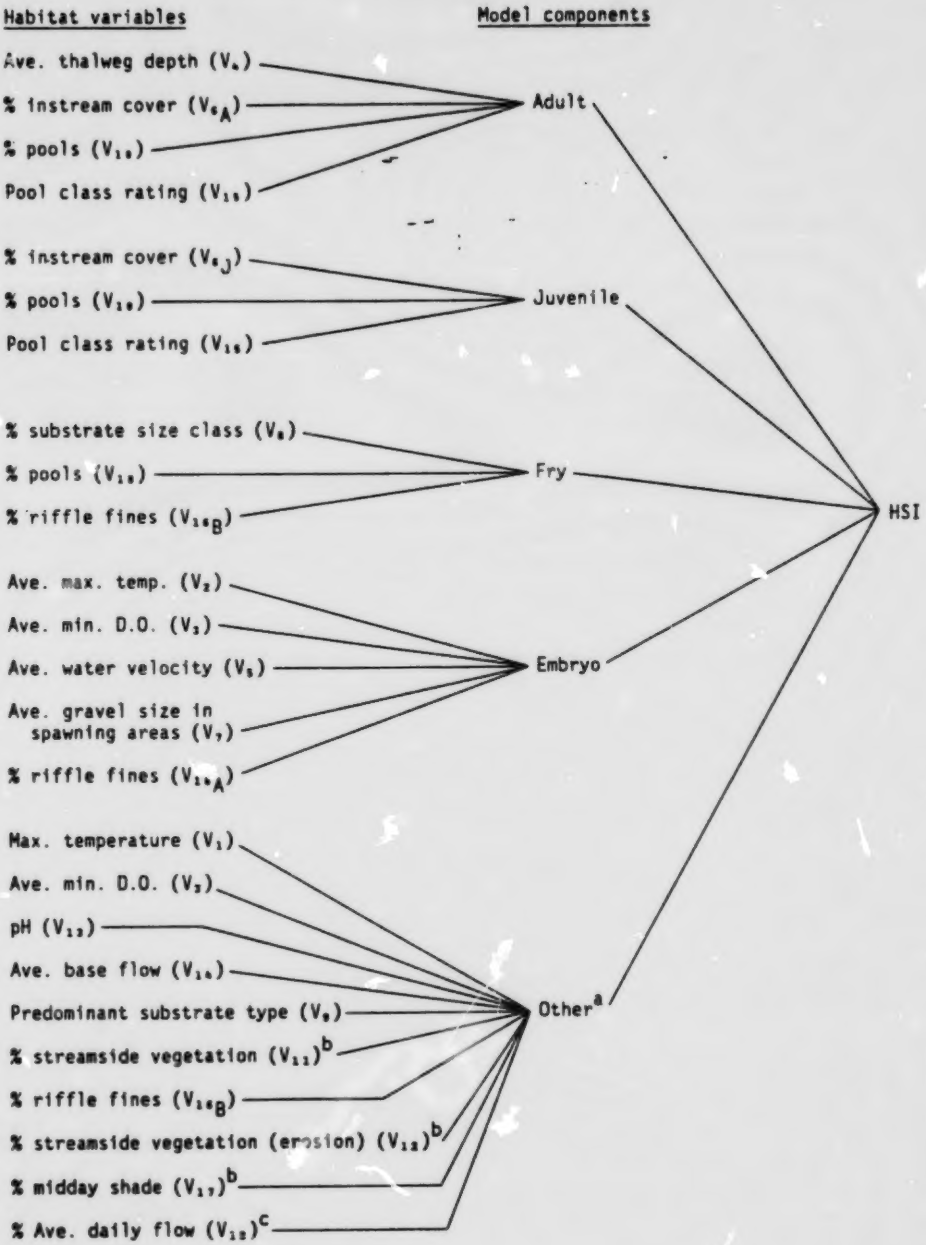
Juvenile. Griffith (1972) reported focal point velocities for juvenile cutthroat in Idaho of between 10 and 12 cm/sec, with a maximum velocity of 22 cm/sec. Metabolic rates are highest between 11 and 21° C, with an apparent optimal temperature of between 15 and 20° C (Dickson and Kramer 1971). In steelhead streams, temperatures should be < 13 but > 4° C (optimal 7 to 10° C) from March until June for normal smoltification to occur (Wagner 1974; Adams et al. 1975).

Common types of cover for juvenile trout are upturned roots, logs, debris piles, overhanging banks, riffles, and small boulders (Bustard and Narver 1975a). Young salmonids occupy different habitats in winter than in summer, with log jams and rubble important as winter cover. Wesche (1980) observed that larger cutthroat trout (> 15 cm long) and juveniles (≤ 15 cm) tended to use instream substrate cover more often than they used streamside cover (undercut banks and overhanging vegetation). However, juvenile brown trout preferred streamside cover. An area of cover ≥ 15% of the total habitat area appears to provide adequate cover for juvenile trout.

Because juvenile rainbow trout occupy habitats contiguous with adults, their temperature and oxygen requirements are assumed to be similar.

HABITAT SUITABILITY INDEX (HSI) MODELS

Figure 1 illustrates the assumed relationships among model variables, components, and the HSI for the rainbow trout model.


Habitat variables
Model components
Ave. thalweg depth (V_4)
% instream cover (V_{6_A})
% pools (V_{10})
Pool class rating (V_{15})
Adult
% instream cover (V_{6_J})
% pools (V_{10})
Pool class rating (V_{15})
Juvenile
% substrate size class (V_8)
% pools (V_{10})
% riffle fines (V_{16_B})
Fry
HSI
Ave. max. temp. (V_2)
Ave. min. D.O. (V_3)
Ave. water velocity (V_5)
Ave. gravel size in spawning areas (V_7)
% riffle fines (V_{16_A})
Embryo
Max. temperature (V_1)
Ave. min. D.O. (V_3)
pH (V_{13})
Ave. base flow (V_{14})
Predominant substrate type (V_9)
% streamside vegetation (V_{11})[b]
% riffle fines (V_{16_B})
% streamside vegetation (erosion) (V_{12})[b]
% midday shade (V_{17})[b]
% Ave. daily flow (V_{18})[c]
Other[a]

[a] Variables that affect all life stages.

[b] Optional variables.

[c] Steelhead variable.

Figure 1. Diagram illustrating the relationship among model variables, components, and HSI.

Model Applicability

Geographic area. The following models are applicable over the entire North American range of the rainbow trout.

Season. The model rates the year-round freshwater habitat of rainbow trout.

Cover types. The model is applicable to freshwater riverine or lacustrine habitats.

Minimum habitat area. Minimum habitat area is the minimum area of continuous habitat that is required for a species to live and reproduce. Because trout can move considerable distances to spawn or locate suitable summer or winter rearing habitat, no attempt has been made to define a minimum amount of habitat for the species.

Verification level. An acceptable level of performance for this rainbow trout model is for it to produce an index between 0 and 1 that the authors and other biologists familiar with rainbow trout ecology believe is positively correlated with long term carrying capacity of the habitat. Model verification consisted of testing the model outputs from sample data sets developed by the authors to simulate rainbow trout habitat of high, medium, and low quality and model review by rainbow trout experts.

Model Description

The HSI model consists of five components: Adult (C_A); Juvenile (C_J); Fry (C_F); Embryo (C_E); and Other (C_O). Each life stage component contains variables specifically related to that component. The component C_O contains variables related to water quality and food supply that affect all life stages of rainbow trout.

The model utilizes a modified limiting factor procedure. This procedure assumes that model variables and components with suitability indices in the average to good range, > 0.4 but < 1.0, can be compensated for by higher suitability indices of other related model variables and components. However, variables and components with suitabilities ≤ 0.4 cannot be compensated for and, thus, become limiting factors for the habitat suitability.

Adult component. Variable V_6, percent instream cover, is included because standing crops of adult trout are assumed to be related to the amount of cover available based on studies of brook and cutthroat trout. Percent pools (V_{10}) is included because pools provide cover and resting areas for adult trout. Variable V_{10} also quantifies the amount of pool habitat that is needed. Variable V_{11}, pool class rating, is included because pools differ in the amount and quality of escape cover, winter cover, and resting areas that they provide. Average thalweg depth (V_4) is included because average water depth affects the amount and quality of pools and instream cover available to adult trout and the migratory access to spawning and rearing areas.

Juvenile component. Variables V_6, percent instream cover; V_{10}, percent pools; and V_{15}, pool class rating are included in the juvenile component for the same reasons listed above for the adult component. Juvenile rainbow trout use these essential stream features for escape cover, winter cover, and resting areas.

Fry component. Variable V_8, percent substrate size class, is included because trout fry utilize substrate as escape cover and winter cover. Variable V_{10}, percent pools, is included because fry use the shallow, slow water areas of pools and backwaters as resting and feeding stations. Variable V_{16}, percent riffle fines, is included because the percent fines affects the ability of the fry to utilize the rubble substrate for cover.

Embryo component. It is assumed that habitat suitability for trout embryos depends primarily on average maximum water temperature, V_2; average minimum dissolved oxygen, V_3; average water velocity, V_5; gravel size in spawning areas, V_7; and percent riffle fines, V_{16}. Water velocity (V_5), gravel size (V_7), and percent fines (V_{16}) are interrelated factors that effect the transport of dissolved oxygen to the embryo and the removal of metabolic waste products from the embryo. In addition, the presence of too many fines in the redds blocks movement of the fry from the incubating gravels to the stream.

Other component. This component contains model variables for two subcomponents, water quality and food supply, that affect all life stages. The subcomponent water quality contains four variables: maximum temperature (V_1); average minimum dissolved oxygen (V_3); pH (V_{13}); and average base flow (V_{14}). The waterflow of all streams fluctuates on a seasonal cycle, and a correlation exists between the average annual daily streamflow and the annual low base flow period. Average base flow (V_{14}) is included to quantify the relationship between annual water flow fluctuations and trout habitat suitability. These four variables affect the growth and survival of all life stages except embryos, whose water quality requirements are included with the embryo component. The subcomponent food supply contains three variables: dominant substrate type (V_9); percent streamside vegetation (V_{11}); and percent riffle fines (V_{16}). Predominant substrate type (V_9) is included because the abundance of aquatic insects, an important food item for rainbow trout, is correlated with substrate type. Variable V_{16}, percent fines in riffle-run and spawning areas, is included because the presence of excessive fines in riffle-run areas reduces the production of aquatic insects. Variable V_{11} is included because allochthonous materials are an important source of nutrients in cold, unproductive trout streams.

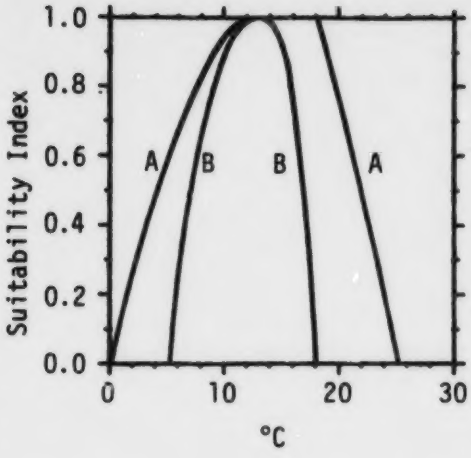
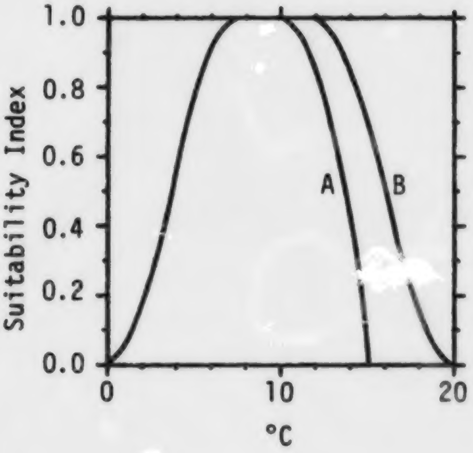
Variables V_{12}, V_{17}, and V_{18} are optional variables to be used only when needed and appropriate. Streamside vegetation, V_{12}, is an important means of controlling soil erosion, a major source of fines in streams, and for input of terrestrial insects. Variable V_{17}, percent midday shade, is included because the amount of shade can affect water temperature and photosynthesis in streams. Average daily flows, V_{18}, are associated with rapid upstream migration of steelhead adults. Variables V_{12} and V_{17} are used primarily for streams ≤ 50 m wide where temperature, photosynthesis, or erosion problems occur or when changes in the riparian vegetation are part of a potential project plan. Variable V_{18} is used only for habitat evaluation for spawning migration of steelhead trout.

Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for the 18 model variables. Equations and instructions for combining groups of variable SI scores into component scores and component scores into rainbow trout HSI scores are included.

The graphs were constructed by quantifying information on the effect of each habitat variable on the growth, survival, or biomass of rainbow trout. The curves were built on the assumption that increments of growth, survival, or biomass plotted on the y-axis of the graph could be directly converted into an index of suitability from 0.0 to 1.0 for the species, with 0.0 indicating unsuitable conditions and 1.0 indicating optimal conditions. Graph trend lines represent the authors' best estimate of suitability for the various levels of each variable. The graphs have been reviewed by biologists familiar with the ecology of the species, but some degree of SI variability exists. The user is encouraged to modify the shape of the graphs when existing regional information indicates that the variable suitability relationship is different from that illustrated.

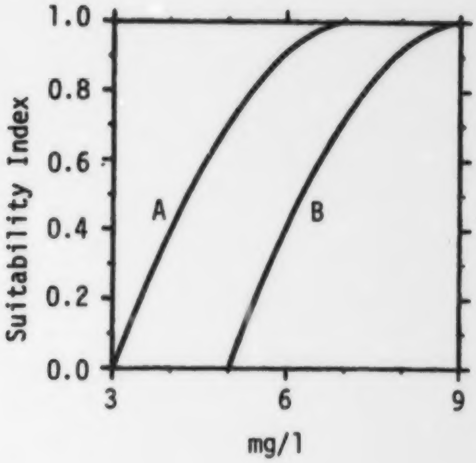
The habitat measurements and the SI graph construction are based on the premise that extreme, rather than average, values of a variable most often limit the carrying capacity of a habitat. Thus, extreme conditions, such as maximum temperatures and minimum dissolved oxygen levels, are often used in the graphs to derive the SI values for the model. The letters R and L in the habitat column identify variables used to evaluate riverine (R) or lacustrine (L) habitats.

Habitat	**Variable**		**Suitability Graph**
R,L	V_1	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry), and during upstream migrations of adult steelhead. For lacustrine habitats, use the temperature strata nearest to optimal in dissolved oxygen zones > 3 mg/l. A = resident rainbow trout B = migrating adult steelhead	
R	V_2	Average maximum water temperature (°C) during embryo development (all rainbows) and during the March to June smoltification period (steelhead juveniles). A = steelhead smolts B = embryos	

R,L V_3 Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo).

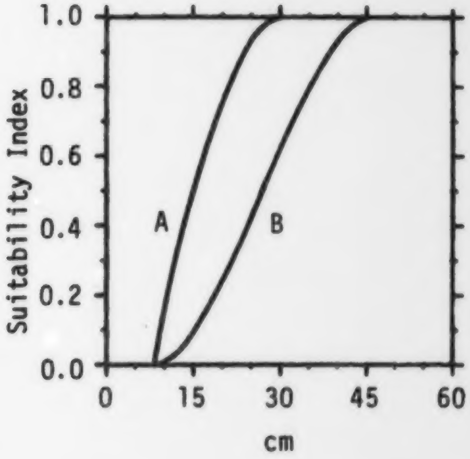
For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l.

A = ≤ 15° C
B = > 15° C

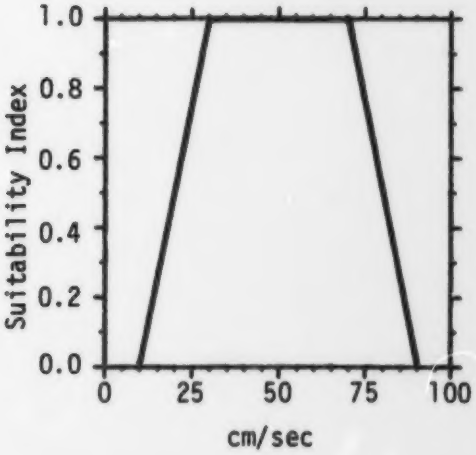


R V_4 Average thalweg depth (cm) during the late growing season low water period (adult).

A = ≤ 5 m stream width
B = > 5 m stream width

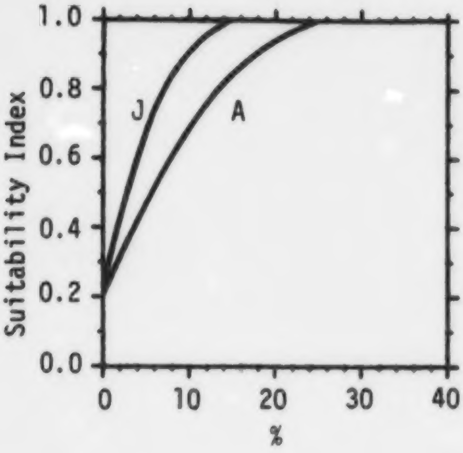


R V_5 Average velocity (cm/sec) over spawning areas during embryo development.



R V_6 Percent instream cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.

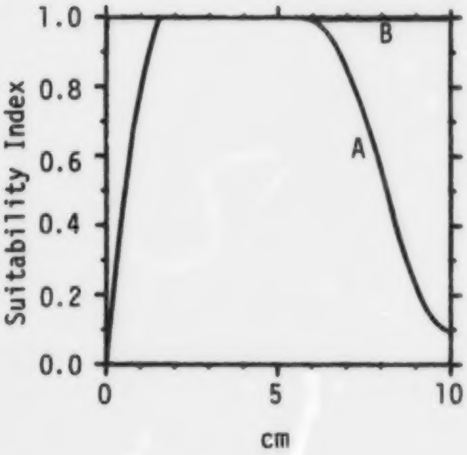
J = juveniles
A = adults

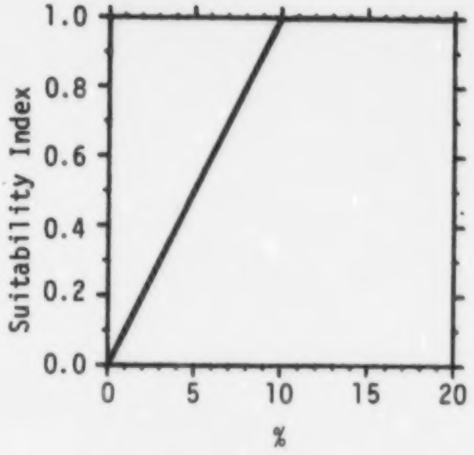
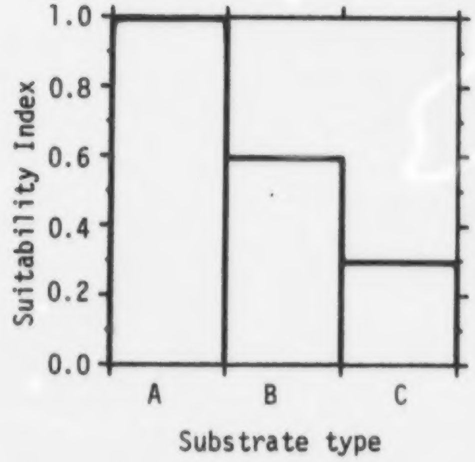


R V_7 Average size of substrate (cm) in spawning areas, preferably during the spawning period.

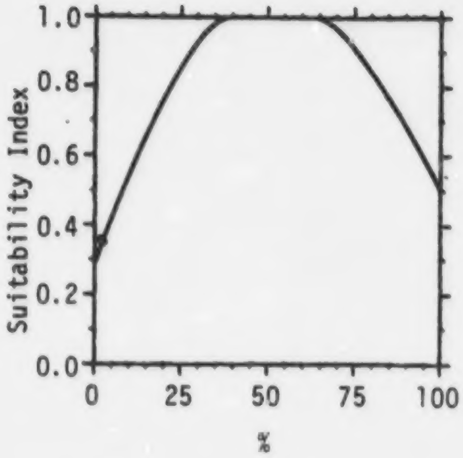
A = average size of spawner < 50 cm
B = average size of spawner ≥ 50 cm

To derive an average value for use with graph V_7, include areas containing the best spawning substrate sampled until all potential spawning sites are included or until the sample contains an area equal to 5% of the total rainbow habitat being evaluated.



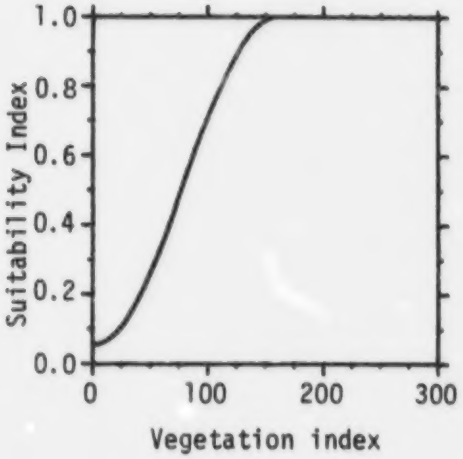
R	V_8	Percent substrate size class (10 to 40 cm) used for winter and escape cover by fry and small juveniles.	
R	V_9	Predominant (≥ 50%) substrate type in riffle-run areas for food production. A) Rubble or small boulders (or aquatic vegetation in spring areas) predominant; limited amounts of gravel, large boulders, or bedrock. B) Rubble, gravel, boulders, and fines occur in approximately equal amounts, or gravel is predominant. Aquatic vegetation may or may not be present. C) Fines, bedrock, or large boulders are predominant. Rubble and gravel are insignificant (≤ 25%).	

R V_{10} Percent pools during the late growing season low water period.

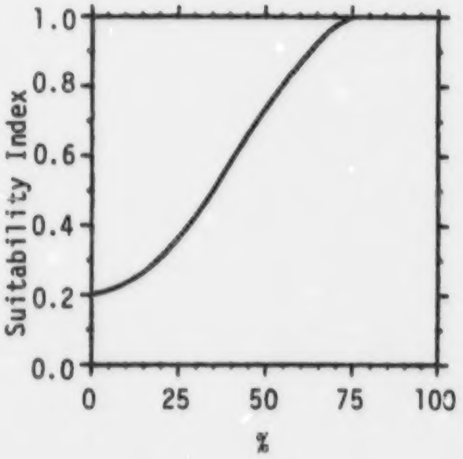


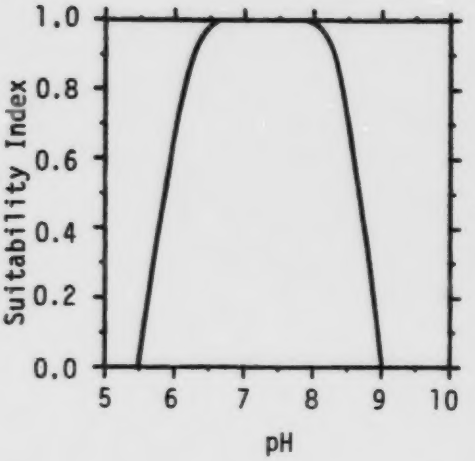
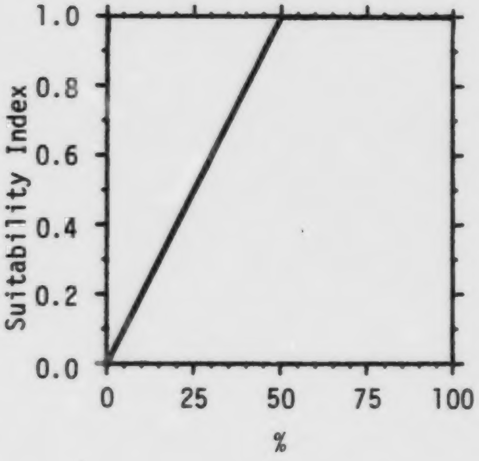
R V_{11} Average percent vegetational ground cover and canopy closure (trees, shrubs, and grasses-forbs) along the streambank during the summer for allochthonous input. Vegetation Index = 2(% shrubs) + 1.5(% grasses) + (% trees).

(For streams ≤ 50 m wide)



R V_{12} (Optional) Average percent rooted vegetation and stable rocky ground cover along stream bank.

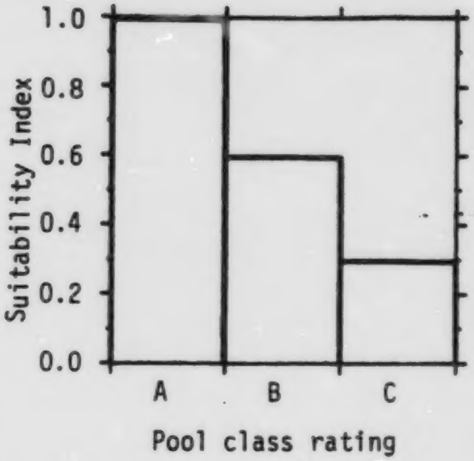


R,L	V_{13}	Annual maximal or minimal pH. Use the measurement with the lowest SI value. For lacustrine habitats, measure pH in the zone with the best combination of dissolved oxygen and temperature.	
R	V_{14}	Average annual base flow regime during the late summer or winter low flow period as a percentage of the average annual daily flow.	

R V_{15} Pool class rating during the late growing season low flow period. The rating is based on the % of the area that contains pools of the three classes described below:

A) ≥ 30% of the area is comprised of 1st-class pools.
B) ≥ 10% but < 30% of the area is 1st-class pools or ≥ 50% is 2nd-class pools.
C) < 10% of the area is 1st-class pools and < 50% is 2nd-class pools.

(See pool class descriptions below)



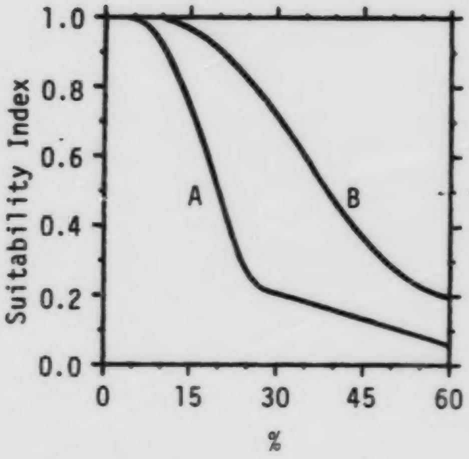
- First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscured due to depth, surface turbulence, or the presence of structures, such as logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

- Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscured due to surface turbulence, depth, or the presence of structures. Typical second-class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

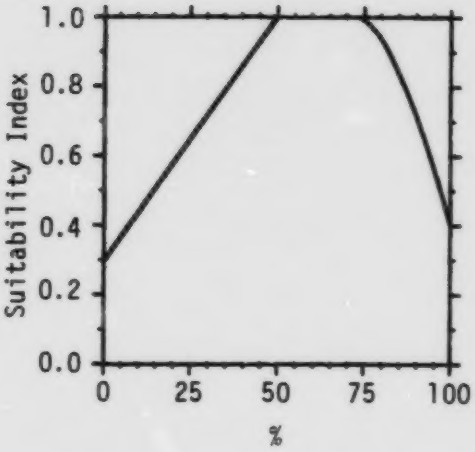
- Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to a very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structures. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. The entire bottom area of the pool is visible.

R V_{16} Percent fines (< 3 mm) in riffle-run and spawning areas during average summer flows.

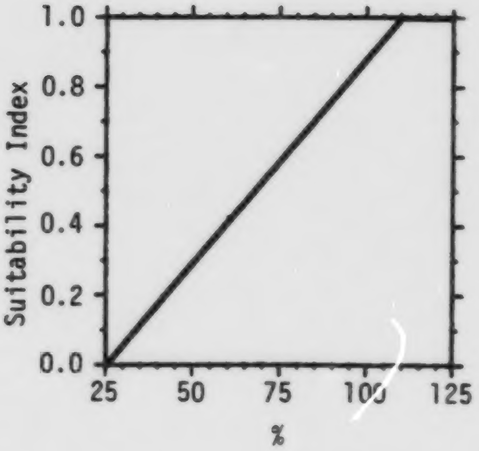
A = spawning
B = riffle-run



R V_{17} (Optional) Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use for cold (< 18° C max. temp.), unproductive streams.



R V_{18} (Optional) Percent average daily flow during the season of upstream migration of adult steelhead.



An HSI based on the concept of a limiting factor can be obtained for a particular life stage of rainbow trout, or all life stages combined, by selecting the lowest suitability index (SI) for the appropriate listed habitat variables as is done in Table 1.

Alternate models and mathematical methods of aggregating SI's into life stage and species HSI's are presented in the following pages.

Table 1. Matrix table for displaying suitability indices (SI's) for rainbow trout habitat variables.

	SI's				
Variables	Adult	Embryo	Fry	Juvenile	Other
V_1 Maximum temperature					X
V_2 Maximum temperature (embryo)		X			
V_3 Minimum dissolved O_2		X			X
V_2 Average thalweg depth	X				
V_5 Average velocity (spawning)		X			
V_6 % cover	X			X	
V_7 Substrate size (spawning)		X			
V_8 % substrate class			X		
V_9 Substrate type (food)					X
V_{10} % pools	X		X	X	
V_{11} % riparian vegetation					X
V_{12} % ground cover (erosion)[a]					
V_{13} Maximum-minimum pH					X
V_{14} Average annual base flow					X
V_{15} Pool class	X			X	
V_{16} % fines		X	X		X
V_{17} % shade[a]					
V_{18} % average daily flow[a]					

[a] Optional variables.

Data sources and the assumptions used to construct the suitability index graphs for rainbow trout HSI models are presented in Table 2.

Riverine Model

This model uses a life stage approach with five components: adult; juvenile; fry; embryo; and other.

Adult (C_A). C_A variables: V_4; V_5; V_{10}; V_{15}; V_{1B}; and V_{18}

Case 1: Where V_6 is $> (V_{10} \times V_{15})^{1/2}$,

$$C_A = [V_4 \times V_6 (V_{10} \times V_{15})^{1/2}]^{1/3}$$

Case 2: Where V_6 is $\leq (V_{10} \times V_{15})^{1/2}$,

$$C_A = [V_4 (V_{10} \times V_{15})^{1/2}]^{1/2}$$

Case 3: Steelhead (C_{AS})

$$C_{AS} = (C_A \times V_{1B} \times V_{18})^{1/3}$$

If V_4 or $(V_{10} \times V_{15})^{1/2}$ is ≤ 0.4 in either equation, then C_A = the lowest factor score.

Juvenile (C_J). C_J variables: V_6; V_{10}; V_{15}; and V_{2A}

Case 1:

$$C_J = \frac{V_6 + V_{10} + V_{15}}{3}$$

Or, if any variable is ≤ 0.4, C_J = the lowest variable score.

Table 2. Literature sources and assumptions for rainbow trout suitability indices.

Variable	and source[a]	Assumptions
V_1	Black 1953 Garside and Tait 1958 Dickson and Kramer 1971 Hanel 1971 May 1973 Cherry et al. 1977	Average maximal daily water temperatures have a greater effect on trout growth and survival than minimal temperatures. The temperature that supports the greatest scope of activity is optimal. In addition, the temperature range associated with rapid migration rates for adult steelhead is optimal.
V_2	Snyder and Tanner 1960 Calhoun 1966 Zaugg and McLain 1972 Zaugg and Wagner 1973 Wagner 1974	The average maximal daily water temperature during the embryo and smoltification development periods that is related to the highest survival of embryos and normal development of smolts is optimal. Temperatures that reduce survival or development of smolts are suboptimal.
V_3	Randall and Smith 1967 Doudoroff and Shumway 1970 Trojnar 1972 Sekulich 1974	The average minimal daily dissolved oxygen level during embryo development and the late growing season that is related to the greatest growth and survival of rainbow trout and trout embryos is optimal. Dissolved oxygen concentrations that reduce survival and growth are suboptimal.
V_4	Delisle and Eliason 1961 Estimated by authors.	Average thalweg depths that provide the best combination of pools, instream cover, and instream movement of adult trout are optimal.
V_5	Delisle and Eliason 1961 Thompson 1972 Hooper 1973 Silver et al. 1963	The average velocities over spawning areas affect habitat suitability because dissolved oxygen is carried to, and waste products are carried away from, the developing embryos. Average velocities that result in the highest survival of embryos are optimal. Velocities that result in reduced survival are suboptimal.

Table 2. (continued)

Variable and source[a]		Assumptions
V_6	Boussu 1954 Elser 1968 Lewis 1969 Wesche 1980	Trout standing crops are correlated with the amount of usable cover. Usable cover is associated with water ≥ 15 cm deep and velocities ≤ 15 cm/sec. These conditions are associated more with pool than with riffle conditions. The best ratio of habitat conditions is approximately 50% pool area to 50% riffle area. Not all of the area of a pool provides usable cover. Thus, it is assumed that optimal conditions exist when usable cover comprises < 50% of the total stream area.
V_7	Orcutt et al. 1968 Bjornn 1969 Phillips et al. 1975 Duff 1980	The average size of spawning gravel that is correlated with the best water exchange rates, proper redd construction, and highest fry survival is assumed to be optimal. The percent total spawning area needed to support a good non-anadromous trout population was calculated from the following assumptions: 1. Excellent riverine trout habitat supports about 500 kg/ha. 2. Spawners comprise about 80% of the weight of the population. 500 kg x 80% = 400 kg of spawners. 3. Rainbow adults average about 0.2 kg each. $\frac{400\ \text{kg}}{0.2\ \text{kg}} = 2{,}000$ adult spawners per hectare 4. There are two adults per redd. $\frac{2{,}000}{2} = 1{,}000$ pairs

Table 2. (continued)

Variable and source^a	Assumptions
	5. Each redd covers ≥ 0.5 m^2. $1{,}000 \times 0.5 \geq 500$ m^2/ha 6. There are 10,000 m^2 per hectare. $\frac{500}{10{,}000}$ = 5% of total area
V_8 Hartman 1965 Everest 1969 Bustard and Narver 1975a	The substrate size range selected for escape and winter cover by trout fry and small juveniles is assumed to be optimal.
V_9 Pennak and Van Gerpen 1947 Hynes 1970 Binns and Eiserman 1979	The predominant substrate type containing the greatest numbers of aquatic insects is assumed to be optimal for insect production.
V_{10} Elser 1968 Fortune and Thompson 1969 Hunt 1971	The percent pools during late summer low flows that is associated with the greatest trout abundance is optimal.
V_{11} Idyll 1942 Delisle and Eliason 1961 Chapman 1966 Hunt 1971	The average percent vegetation along the streambank is related to the amount of allochthonous materials deposited annually in the stream. Shrubs are the best source of allochthonous materials, followed by grasses and forbs, and then trees. The vegetational index is a reasonable approximation of optimal and suboptimal conditions for most trout stream habitats.
V_{12} Oregon/Washington Interagency Wildlife Conference 1979 Raleigh and Duff 1980	The average percent rooted vegetation and rocky ground cover that provides adequate erosion control to the stream is optimal.
V_{13} Hartman and Gill 1968 Behnke and Zarn 1976	The average annual maximal or minimal pH levels related to high survival of trout are optimal.

Table 2. (concluded)

	Variable and source[a]	Assumptions
V_{14}	Duff and Cooper 1976 Binns 1979	Flow variations affect the amount and quality of pools, instream cover, and water quality. Average annual base flows associated with the highest standing crops are optimal.
V_{15}	Lewis 1969	Pool classes associated with the highest standing crops of trout are optimal.
V_{16}	Cordone and Kelly 1961 Bjornn 1969 Phillips et al. 1975 Crouse et al. 1981	The percent fines associated with the highest standing crops of food organisms, embryos, and fry in each designated area are optimal.
V_{17}	Sabean 1976, 1977 Anonymous 1979	The percent of shaded stream area during midday that is associated with optimal water temperatures and photosynthesis rates is optimal.[b]
V_{18}	Withler 1966 Everest 1973	The above average daily flows (freshets) associated with rapid upstream migrations of steelhead adults are optimal. Low flows associated with migration delays are suboptimal.

[a] The above references include data from studies on related salmonid species. This information has been selectively used to supplement, verify, or fill data gaps on the habitat requirements of rainbow trout.

[b] Shading is highly variable from site to site. Low elevations with warmer climates require abundant shading to maintain cool waters. At higher elevations with cooler climates, the absence of shading is beneficial because it results in higher photosynthetic rates and warming of water to a more optimal temperature.

Case 2: Steelhead (C_{JS})

$$C_{JS} = (C_J \times V_{2A})^{1/2}$$

Fry (C_F). C_F variables: V_8; V_{10}; and V_{16}

$$C_F = [V_{10} (V_8 \times V_{16})^{1/2}]^{1/2}$$

Or, if V_{10} or $(V_8 \times V_{16})^{1/2}$ is ≤ 0.4, C_F = the lowest factor score.

Embryo (C_E). C_E variables: V_2; V_3; V_5; V_7; and V_{16}

Steps in calculating C_E:

A. A potential spawning site is a ≥ 0.5 m² area of gravel, with an average diameter of 0.3 to 8.0 cm, covered by flowing water ≥ 15 cm deep. For steelhead, increase the spawning site area from 0.5 to 2.0 m and the gravel size to 0.3 to 10.0 cm. At each spawning site sampled, record:

1. The average water velocity over the site;
2. The average size of all gravel 0.3 to 8.0 cm;
3. The percentage of fines < 0.3 cm in the gravel; and
4. The total area.

B. Derive a spawning site suitability index (V_s) for each site by combining V_5, V_7, and V_{16} values for each site as follows.

$$V_s = (V_5 \times V_7 \times V_{16})^{1/3}$$

C. Derive a weighted average ($\bar{V}_s$) for all sites included in the sample.

Select the best V_s scores until all sites are included or until a total spawning area equal to, but not exceeding, 5% of the total trout habitat has been included, whichever comes first.

$$\bar{V}_s = \frac{\sum_{i=1}^{n} A_i V_{si}}{\text{total habitat area}} / 0.05 \text{ (output cannot exceed 1.0)}$$

where A_i = the area of each spawning site in m², but ΣA_i cannot exceed 5% of the total habitat

V_{si} = the individual SI's from the best spawning areas until all spawning sites have been included or until the SI's from an area equal to 5% of the total habitat being evaluated have been included, whichever occurs first.

Disregard area restrictions for steelhead. Because advanced juvenile and adult steelhead mature in the ocean, they can theoretically utilize a much greater spawning area than nonanadromous rainbows.

D. Derive C_E

C_E = the lowest score of V_2, V_3, or $\bar{V}_s$

Other (C_O). C_O variables: V_1; V_3; V_9; V_{11}; V_{12}; V_{13}; V_{14}; V_{16}; and V_{17}

$$C_O = \frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2} \times (V_1 \times V_3 \times V_{12} \times V_{13} \times V_{14} \times V_{17})^{1/N} {}^{1/2}$$

where N = the number of variables within the brackets. Note that variables V_{12} and V_{17} are optional and, therefore, can be omitted (see page 13).

HSI determination. HSI scores can be derived for a single life stage, a combination of two or more life stages, or all life stages combined. In all cases, except for the embryo component (C_E), an HSI is obtained by combining one or more life stage component scores with the C_O component score.

1. Equal Component Value Method. The equal component value method assumes that each component exerts equal influence in determining the HSI. This method should be used to determine the HSI unless information exists that suggests that individual components should be weighted differently. Components: C_A; C_J; C_F; C_E; and C_O

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_O)^{1/N}$$

where N = the number of components in the equation

Or, if any component is ≤ 0.4, the HSI = the lowest component value.

Solve the equation for the number of components included in the evaluation. There will be a minimum of two; one or more life stage components and the component (C_O), unless only the embryo life stage (C_E) is being evaluated, in which case, the HSI = C_E.

2. Unequal Component Value Method. This method also uses a life stage approach with five components: adult (C_A); juvenile (C_J); fry (C_F); embryo (C_E); and other (C_O). However, the C_O component is divided into two subcomponents, food (C_{OF}) and water quality (C_{OQ}). It is assumed that the C_{OF} subcomponent can either increase or decrease the suitability of the habitat by its effect on growth at each life stage, except embryo. The C_{OQ} subcomponent is assumed to exert an influence equal to the combined influence of all other model components in determining habitat suitability. This method also assumes that water quality is excellent; i.e., $C_{OQ} = 1$. When C_{OQ} is < 1, the HSI is decreased. In addition, when a basis for weighting the individual components exists, model component and subcomponent weights can be increased by multiplying each index value by multiples > 1. Model weighting procedures must be documented.

Components and subcomponents: C_A; C_J; C_F; C_E; C_{OF}; and C_{OQ}

Steps:

A. Calculate the subcomponents C_{OF} and C_{OQ} of C_O

$$C_{OF} = \frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2}$$

$$C_{OQ} = (V_1 \times V_3 \times V_{13} \times V_{14})^{1/4}$$

Or, if any variable is ≤ 0.4, C_{OQ} = the value of the lowest variable.

B. Calculate the HSI by either the noncompensatory or the compensatory option.

Noncompensatory option. This option assumes that degraded water quality conditions cannot be compensated for by good physical habitat conditions. This assumption is most likely to be true for small streams ($\leq$ 5 m wide) and for persistently degraded water quality conditions.

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N} \times C_{OQ}$$

Or, if any component is $\leq$ 0.4, the HSI = the lowest component value.

where N = the number of components and subcomponents inside the parentheses or, if the model components or subcomponents are weighted, N = the summation of weights selected

For steelhead, substitute C_{AS} and C_{JS} for C_A and C_J.

If only the embryo component is being evaluated, then $HSI = C_E \times C_{OQ}$.

Compensatory option. This method assumes that moderately degraded water quality conditions can be partially compensated for by good physical habitat conditions. This assumption is most useful for large rivers ($\geq$ 50 m wide) and for temporary poor water quality conditions.

1) $HSI' = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N}$

Or, if any component is $\leq$ 0.4, the HSI' = the lowest component value.

where N = the number of components and subcomponents in the equation or, if the model components or subcomponents are weighted, N = the summation of the weights selected

For steelhead, substitute C_{AS} and C_{JS} for C_A and C_J.

2) If C_{OQ} is $<$ HSI', then $HSI = HSI' \times [1 - (HSI' - C_{OQ})]$;
if C_{OQ} is $\geq$ HSI, then HSI = HSI'.

3) If only the embryo component is being evaluated, substitute C_E for HSI' and follow the procedure in Step 2.

Lacustrine Models

The following models are designed to evaluate rainbow trout lacustrine habitat. The lacustrine model contains two components, water quality (C_{WQ}) and reproduction (C_R).

Water Quality (C_{WQ}). C_{WQ} variables: V_1; V_3; and V_{13}

$$C_{WQ} = (V_1 \times V_3 \times V_{13})^{1/3}$$

Or, if the SI scores for V_1 or V_3 are ≤ 0.4, C_{WQ} = the lowest SI score for V_1 or V_3.

Note: Lacustrine rainbows require a tributary stream for spawning and embryo development. If the embryo life stage habitat is included in the evaluation, use the embryo component steps and equations in the riverine model above, except that the area of spawning gravel needed is only about 1% of the total surface area of the lacustrine habitat.

Embryo (C_E). C_E variables: V_2; V_3; V_5; V_7; and V_{16}

$$\bar{V}_s = \frac{\sum_{i=1}^{n} A_i \, V_{si}}{\text{total habitat area}} \ /0.01 \text{ (output cannot be > 1.0)}$$

$$HSI = (C_{WQ} \times C_E)^{1/2}$$

If only the lacustrine habitat is evaluated, the HSI = C_{WQ}.

FWS/OBS-82/10.24
September 1982

HABITAT SUITABILITY INDEX MODELS: BROOK TROUT

by

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PREFACE

The habitat use information and Habitat Suitability Index (HSI) models presented in this document are an aid for impact assessment and habitat management activities. Literature concerning a species' habitat requirements and preferences is reviewed and then synthesized into HSI models, which are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Assumptions used to transform habitat use information into these mathematical models are noted, and guidelines for model application are described. Any models found in the literature which may also be used to calculate an HSI are cited, and simplified HSI models, based on what the authors believe to be the most important habitat characteristics for this species, are presented.

Use of the models presented in this publication for impact assessment requires the setting of clear study objectives and may require modification of the models to meet those objectives. Methods for reducing model complexity and recommended measurement techniques for model variables are presented in Terrell et al. (in press)[1]. A discussion of HSI model building techniques, including the component approach, is presented in U.S. Fish and Wildlife Service (1981).[2]

The HSI models presented herein are complex hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. Results of model performance tests, when available, are referenced; however, models that have demonstrated reliability in specific situations may prove unreliable in others. For this reason, the U.S. Fish and Wildlife Service encourages model users to send comments and suggestions that might help us increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning. Please send comments to:

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[1] Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. W. Williamson (in press). Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the Habitat Evaluation Procedures. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.A.

[2] U.S. Fish and Wildlife Service. 1981. Standards for the development of Habitat Suitability Index models. 103 ESM. U.S. Dept. Int., Fish Wildl. Serv., Div. Ecol. Serv. n.p.

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BROOK TROUT (Salvelinus fontinalis)

HABITAT USE INFORMATION

General

The native range of brook trout (Salvelinus fontinalis Mitchill) originally covered the eastern two-fifths of Canada northward to the Arctic Circle, the New England States, and southward through Pennsylvania, along the crest of the Appalachian Mountains to northeastern Georgia. Western limits included Manitoba southward through the Great Lake States. Reductions in the original range have resulted from environmental changes, such as pollution, siltation, and stream warming due to deforestation (MacCrimmon and Campbell 1969).

Since the late 19th century, brook trout have been introduced into 20 additional States and have sustaining populations in 14 States (MacCrimmon and Campbell 1969). Introductions have not been attempted in most of the central plains and the southern States.

Brook trout can be separated into two basic ecological forms: a short-lived (3-4 years), small (200-250 mm) form, typical of small, cold stream and lake habitats and a long-lived (8-10 years), large (4-6 kg), predaceous form associated with large lakes, rivers, and estuaries. The smaller, short-lived form is typically found south of the Great Lakes region and south of northern New England, while the larger form is located in the northern portion of its native range (Behnke 1980). Although no subspecies designation has been recognized for these two forms, they respond as two different species to environmental interactions influencing life history (Flick and Webster 1976; Flick 1977).

Brook trout can be hybridized artificially with lake trout (to produce a fertile hybrid called splake trout) and with rainbow trout (Buss and Wright 1957). In rare cases, natural hybrids occur between brook trout and brown trout (Salmo trutta); the hybrid is termed tiger trout (Behnke 1980). Behnke (1980) also collected brook trout and bull trout (Salvelinus confluentis) hybrids in the upper Klamath Lake basin, Oregon. Brook trout appear to be sensitive to introductions of brown and rainbow trout and are usually displaced by them. However, brook trout have displaced cutthroat trout and grayling in headwaters and tributaries of western streams (Webster 1975).

Age, Growth, and Food

Brook trout appear to be opportunistic sight feeders, utilizing both bottom-dwelling and drifting aquatic macroinvertebrates and terrestrial insects (Needham 1930; Dineen 1951; Wiseman 1951; Benson 1953; Reed and Bear 1966). Such feeding habits make them particularly susceptible to even moderate turbidity levels, which can reduce their ability to locate food (Bachman 1958; Herbert et al. 1961a, 1961b; Tebo 1975). Drifting forms may be selected over benthic forms when they are available (Hunt 1966). The choice of particular drift organisms is apparently either a function of seasonal availability and/or the overall availability of terrestrial forms in a particular situation. Between age groups, there may be a tendency for selection of food items based on size. In Idaho, age group 0 trout selected smaller drifting organisms (Diptera and Ephemeroptera) with less variation than did older trout, while age group I trout seemed to prefer larger Trichoptera larvae (Griffith 1974). Fish are an important food item in lake populations (Webster 1975).

Reproduction

Age at sexual maturity varies among populations, with males usually maturing before females (Mullen 1958). Male brook trout may mature as early as age 0+ (Buss and McCreary 1960; Hunt 1966). In Wisconsin (Lawrence Creek), the smallest mature male was approximately 8.9 cm (3.5 inches) long (McFadden 1961).

Spawning typically occurs in the fall and has been described by several authors (Greeley 1932; Hazzard 1932; Smith 1941; Brasch et al. 1958, Needham 1961). Spawning may begin as early as late summer in the northern part of the range and early winter in the southern part of the range (Sigler and Miller 1963). The spawning behavior of brook trout is very similar to that of rainbow and cutthroat trout (Smith 1941). In streams and ponds, areas of ground water upwelling appear to be highly preferred (Webster and Eiriksdottier 1976; Carline and Brynildson 1977) and to override substrate size as a site selection factor (Mullen 1958; Everhart 1966). Brook trout can be highly successful spawners in lentic environments in upwelling areas of springs (Webster 1975). Spawning occurs at temperatures ranging from 4.5-10° C (White 1930; Hazzard 1932; McAfee 1966). The fertilized ova are deposited in redds excavated by the female in the stream gravels (Smith 1947). Spawning success is reduced as the amount of fine sediments is increased and the intergravel oxygen concentration is diminished (McFadden 1961; Peters 1965; Harshbarger 1975).

Migration and Anadromy

With the exception of the sea-run New England populations, brook trout migrations are generally limited to movements into headwater streams or tributaries for spawning (Brasch et al. 1958) or relatively short seasonal migrations to avoid temperature extremes (Powers 1929; Scott and Crossman 1973). Some brook trout may spend their entire lives, including spawning periods, within a restricted stream area, as opposed to more migratory salmonids (McFadden et al. 1967). However, some movement upstream or downstream may occur due to space-related aggressive behavior following emergence from the redd (Hunt 1965).

Some coastal populations of brook trout may move into salt water from coastal streams of eastern Canada and northeastern United States. Sea-run individuals caught in salt water may differ in appearance, form, and coloration from trout that have never or have not recently been in salt water (Smith and Saunders 1958). Not all brook trout in the same stream will necessarily move to sea. In a study by White (1940), 79% of the brook trout going to sea were age 2, and the rest were age 3. Smith and Saunders (1958) stated that age 1 brook trout also migrated to the sea.

Smith and Saunders (1958) reported brook trout going to sea on Prince Edward Island during spring and early summer and during fall and early winter. Movement was observed in every month of the year, although very few fish were observed migrating during midwinter and midsummer. Smith and Saunders (1958) observed that approximately half of the brook trout migrating to salt water returned to freshwater within a month. As temperatures decline in freshwater, brook trout tend to spend more time in saltwater, and some may overwinter in saltwater (Smith and Saunders 1958).

Specific Habitat Requirements

Brook trout are the most generalized and adaptable of all *Salvelinus* species. They inhabit small headwater streams, large rivers, ponds, and large lakes in inland and coastal areas. Typical brook trout habitat conditions are those associated with a cold temperate climate, cool spring-fed ground water, and moderate precipitation (MacCrimmon and Campbell 1969). Warm water temperatures appear to be the single most important factor limiting brook trout distribution and production (Creaser 1930; Mullen 1958; McCormick et al. 1972). In a comparative distribution study between brook and brown trout from headwater tributaries of the South Platte River, Colorado, Vincent and Miller (1969) found that, as the elevation increased and the streams became smaller and colder, brook trout became more abundant.

Optimal brook trout riverine habitat is characterized by clear, cold spring-fed water; a silt-free rocky substrate in riffle-run areas; an approximate 1:1 pool-riffle ratio with areas of slow, deep water; well vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks. Brook trout south of Canada tend to occupy headwater stream areas, especially when rainbow and brown trout are present in the same river system (Webster 1975). They tend to inhabit large rivers in the northern portion of their native range (Behnke 1980).

Optimal lacustrine habitat is characterized as clear, cold lakes and ponds that are typically oligotrophic. Brook trout are typically stream spawners, but spawning commonly occurs in gravels surrounding spring upwelling areas of lakes and ponds.

Cover is recognized as one of the basic and essential components of trout streams. Boussu (1954) was able to increase the number and weight of trout in stream sections by adding artificial brush cover and to decrease numbers and weight by removing brush cover and undercut banks. Lewis (1969) found that the amount of cover present was important in determining the number of trout in sections of a Montana stream. Cover for trout consists of areas of low stream bottom visibility, suitable water depths (> 15 cm), and low current velocity (< 15 cm/s) (Wesche 1980). Cover can be provided by overhanging vegetation, submerged vegetation, undercut banks, instream objects (stumps, logs, roots, and large rocks), rocky substrate, depth, and water surface turbulence (Giger 1973). In a study to determine the amount of shade utilized by brook, rainbow, and brown trout, Butler and Hawthorne (1968) reported that rainbow trout showed the lowest preference for shade produced by artificial surface cover. Brown trout showed the highest use of shade while brook trout were intermediate between brown and rainbow trout. Brook trout in two Michigan streams showed a strong preference for overhead cover along the stream margin (Enk 1977). The major limiting factor for brook trout in these streams was bank cover.

Canopy cover is important in maintaining shade for stream temperature control and in providing allochthonous materials to the stream. Too much shade, however, can restrict primary productivity in a stream. Stream temperatures can be increased or decreased by controlling the amount of shade. About 50-75% midday shade appears optimal for most small trout streams (Anonymous 1979). Shading becomes less important as stream gradient and size increases. In addition, a well vegetated riparian area helps to control watershed erosion. In most cases, a buffer strip about 30 m deep, 80% of which is either well vegetated or has stable rocky stream banks, will provide adequate erosion control and maintain undercut stream banks characteristic of good trout habitat. The presence of fines in riffle-run areas can adversely affect embryo survival, food production, and cover for juveniles.

There is a definite relationship between the annual flow regime and the quality of trout habitat. The most critical period is typically the base flow (lowest flows of late summer to winter). A base flow ≥ 55% of the average annual daily flow is considered excellent, a base flow of 25 to 50% is considered fair, and a base flow of < 25% is considered poor for maintaining quality trout habitat (adapted from Wesche 1974; Binns and Eiserman 1979; Wesche 1980).

Hunt (1976) listed average depth, water volume, average depth of pools, amount of pool area, and amount of overhanging bank cover as the most important parameters relating to brook trout carrying capacity in Lawrence Creek, Wisconsin. The main use of summer cover is probably for predator avoidance and resting. Salmonids occupy different habitat areas in the winter than in the summer (Hartman 1965; Everest 1969; Bustard and Narver 1975a).

In some streams, the major factor limiting salmonid densities may be the amount of adequate overwintering habitat rather than summer rearing habitat (Bustard and Narver 1975a). Everest (1969) suggested that some salmonid population levels were regulated by the availability of suitable overwintering areas. Winter hiding behavior in salmonids is triggered by low temperatures (Chapman and Bjornn 1969; Everest 1969; Bustard and Narver 1975a,b). Bustard and Narver (1975a) indicated that, as water temperatures dropped to 4-8° C, feeding was reduced in young salmonids and most were found within or near cover; few were more than 1 m from potential cover. Everest (1969) found juvenile rainbows 15-30 cm deep in the substrate, which was often covered by 5-10 cm of anchor ice. Lewis (1969) reported that adult rainbow trout tended to move into deeper water during winter. The major advantages in seeking winter cover are prevention of physical damage from ice scouring (Hartman 1965; Chapman and Bjornn 1969) and conservation of energy (Chapman and Bjornn 1969; Everest 1969). A cover area ≥ 25% for adults and ≥ 15% for juveniles of the entire stream habitat appears adequate for most brook trout populations.

Optimum turbidity values for brook trout growth are approximately 0-30 JTU's, with a range of 0-130 JTU's (adapted from Sykora et al. 1972). An accelerated rate of sediment deposition in streams may reduce local brook trout production because of the adverse effects on production of food organisms, smothering of eggs and embryos in the redd, and loss of escape and overwintering habitat.

Brook trout appear to be more tolerant than other trout species to low pH (Dunson and Martin 1973; Webster 1975). Laboratory studies indicate that brook trout are tolerant of pH values of 3.5-9.8 (Daye and Garside 1975). Brook trout fingerlings in Pennsylvania inhabited a bog stream with a pH less than 4.75 and occassionally dropping to 4.0-4.2 (Dunson and Martin 1973). Parsons (1968) reported brook trout inhabiting a stream in Missouri with a pH of 4.1-4.2. Creaser (1930) believed that brook trout tolerated pH ranges greater than the range of most natural waters (4.1-9.5). Menendez (1976) demonstrated that continued exposure to a pH below 6.5 resulted in decreased hatching and growth in brook trout. The selection of spawning sites may be associated with the pH of upwelling water; neutral or alkaline waters (pH 6.7 and 8) were selected by brook trout held at pH levels of 4.0, 4.5, and 5.0 (Menendez 1976). The optimal pH range for brook trout appears to be 6.5-8.0, with a tolerance range of 4.0-9.5.

Brook trout occur in waters with a wide range of alkalinity and specific conductance, although high alkalinity and high specific conductance usually increase brook trout production (Cooper and Scherer 1967). Brook trout populations in the Smoky Mountains, North Carolina, are becoming increasingly restricted to low alkalinity headwater streams, apparently due to competition from introduced rainbow trout (Salmo gairdneri), and are frequently in poor condition (Lennon 1967). The small size of the trout in the headwater areas has been attributed to the infertility of the water, which has been linked to low total alkalinities (10 ppm or less) and TDS values less than 20 ppm. TDS values in the Smoky Mountains are lower than values from similar streams in Shenandoah National Park, Virginia, and the White Mountains National Forest, New Hampshire, where trout populations appear to be more robust.

Headwater trout streams are relatively unproductive. Most energy inputs to the stream are in the form of allochthonous materials, such as terrestrial vegetation and terrestrial insects (Idyll 1942; Chapman 1971; Hunt 1975). Aquatic invertebrates are most abundant and diverse in riffle areas with rubble substrate and on submerged aquatic vegetation (Hynes 1970). However, optimal substrate for maintenance of a diverse invertebrate population consists of a mosaic of gravel, rubble, and boulders with rubble being dominant. The invertebrate fauna is much more abundant and diverse in riffles than in pools (Hynes 1970), but a ratio of about 1:1 of pool to riffle area (about 40-60% pool area) appears to provide an optimum mix of trout food producing and rearing areas (Needham 1940). In riffle areas, the presence of fines (> 10%) reduces the production of invertebrate fauna (based on Cordone and Kelly 1961; Platts 1974).

Adult. The reported upper and lower temperature limits for adult brook trout vary; this may reflect local and regional population acclimation differences. Bean (1909) reported that brook trout will not live and thrive in temperatures warmer than 20° C. McAfee (1966) indicated that brook trout usually do poorly in streams where water temperature exceeds 20° C for extended periods. Brasch et. al (1958) reported that brook trout exposed to temperatures of 25° C for more than a few hours did not survive. Embody (1921) observed brook trout living in temperatures of 24-27° C for short durations and recommended 23.8° C as the maximum tolerable limit. Kendall (1924) agreed that 23.9° C represented the limit of even temporary endurance, but stated that the optimum temperature should not exceed 15.6° C. Hynes (1970) stated that brook trout can withstand temperatures from 0-25.3° C, but acclimation is necessary. The upper tolerable limit is raised by approximately 1° for every 7° rise in acclimation temperature up to 18° C, where it levels off at the absolute limit of 25.3° C. Fish kept at 24° C and above cannot tolerate temperatures as low as 0° C. Seasonal temperature cycles from summer highs to winter lows provide the necessary acclimation period needed to tolerate annual temperature extremes. The overall temperature range of 0-24° C was observed by MacCrimmon and Campbell (1969.

The above upper and lower tolerance limits probably do not reflect the range of temperatures that is most conducive to good growth. Baldwin (1951) cites an optimum growth rate at 14° C. He further contends that 11-16° C is best suited for overall welfare, while trout exist at a relative disadvantage in terms of activity and growth at higher and lower, albeit tolerable, temperatures. Mullen (1958) gave the optimum temperature range for activity and feeding for brook trout as between 12.8° C and 19° C. We assume that the temperature range for brook trout is 0-24° C, with an optimal range for growth and survival of 11-16° C.

Brook trout normally require high oxygen concentrations with optimum conditions at dissolved oxygen concentrations near saturation and temperatures above 15° C. Local or temporal variations should not decrease to less than 5 mg/l (Mills 1971). Dissolved oxygen requirements vary with age of fish, water temperature, water velocity, activity level, and concentration of substances in the water (McKee and Wolf 1963). As temperatures increase, the dissolved oxygen saturation level in the water decreases, while the dissolved oxygen requirements of the fish increases. As a result, an increase in temperature resulting in a decrease in dissolved oxygen can be detrimental to the fish. Optimum oxygen levels for brook trout are not well documented but appear to be ≥ 7 mg/l at temperatures < 15° C and ≥ 9 mg/l at temperatures ≥ 15° C. Doudoroff and Shumway (1970) demonstrated that swimming speed and growth rates for salmonids declined with decreasing dissolved oxygen levels. In the summer (temperatures ≥ 10° C), cutthroat trout generally avoid water with dissolved oxygen levels of less than 5 mg/l (Trojnar 1972; Sekulich 1974). Fry (1951) stated that the lowest dissolved oxygen concentrations where brook trout can exist is 0.9 ppm at 10° C and 1.6-1.8 ppm at 20° C. Embody (1927) contends that the dissolved oxygen concentration should not be less than 3 cc per liter (4.3 ppm).

Elson (1939) reported that brook trout prefer moderate flows. Griffith (1972) reported that focal point velocities for adult brook trout in Idaho ranged from 7-11 cm/sec, with a maximum of 25 cm/sec. In a Wyoming study, 95% of all brook trout observed were associated with point velocities of less than 15 cm/sec (Wesche 1974).

The carrying capacity of adult brook trout in streams is dependent, at least in part, on cover provided by pools, undercut banks, submerged brush and logs, large rocks, and overhanging vegetation (Saunders and Smith 1955, 1962; Elwood and Waters 1969; O'Connor and Power 1976). Enk (1977) reported that the biomass and number of brook trout ≥ 150 mm in size were significantly correlated with bank cover in two Michigan streams. Wesche (1980) reported that cover for adult trout should be located in stream areas with water depths ≥ 15 cm and velocities of < 15 cm/sec. We assume that an area ≥ 25% of the total stream area occupied by brook trout will provide adequate cover.

Embryo. Temperatures in the range of 4.5-11.5° C have been reported as optimum for egg incubation (MacCrimmon and Campbell 1969). Length of egg incubation is about 45 days at 10° C, 165 days at 2.8° C (Brasch et al. 1958), and 28 days at 14.8° C (Embody 1934). Brook trout eggs develop slightly faster than brown trout eggs at 2° C or colder, but the reverse is true at 3° C or above (Smith 1947). We assume that the range of acceptable temperatures for brook trout embryos is similar to that for cutthroat trout (Salmo clarki).

Dissolved oxygen concentrations should not fall below 50% saturation in the redd for embryo development (Harshbarger 1975). We assume that oxygen requirements for embryos are similar to those of adults. Peters (1965) observed high mortality rates when water velocity in the redd was reduced. Water velocity is important in flushing out fines in the redds. Because brook trout can successfully spawn in spawning areas of lakes, velocity is not necessary for successful spawning as long as oxygen levels are high and the redd is free of silt. Spawning velocities for brook trout range from 1 cm/sec (Smith 1973) to 92 cm/sec (Thompson 1972; Hooper 1973). Spawning velocities measured for brook trout in Wyoming ranged from 3-34 cm/sec (Reiser and Wesche 1977).

Reiser and Wesche (1977) stated that optimum substrate size for brook trout embryos ranges from 0.34-5.05 cm. Duff (1980) reported a range of suitable spawning gravel size of 3-8 cm in diameter for trout. Most workers agree that both water velocity and dissolved oxygen in the intergravel environment determine the adequacy of the substrate for the hatching and survival of salmonid embryos and fry. Increases in sediment that alter gravel permeability reduces velocities and intergravel dissolved oxygen availability to the embryo and results in smothering of eggs (Tebo 1975). In a California study, brook trout survival was lower as the volume of materials less than 2.5 mm in diameter increased (Burns 1970). In a 30% sand and 70% gravel mixture, only 28% of implanted steelhead embryos hatched; of those that hatched, only 74%

emerged (Bjornn 1971; Phillips et al. 1975). We assume that suitable spawning gravel conditions include gravels 3-8 cm in size (depending on size of spawners) with ≤ 5% fines.

Fry. McCormick et al. (1972) cited temperature as an important limiting factor of growth and distribution of young brook trout. Fry emerge from gravel redds from January to April, depending on the local temperature regime (Brasch et al. 1958). Temperatures from 9.8-15.4° C were considered suitable, with 12.4-15.4° C optimum; temperatures greater than 18° C were considered detrimental. The optimum temperature for brook trout fry, in a laboratory study, was between 8-12°C (Peterson et al. 1979). Upper lethal temperatures are between 21 and 25.8° C (Brett 1940), possibly a reflection of different acclimatization temperatures. Latta (1969) reported that upwelling ground water was an important consideration for the well-being of fry in streams; Carline and Brynildson (1977) reported the same situation for fry in spring ponds. Menendez (1976) found that fry survival increased as pH increased from 5 to 6.5. Griffith (1972) reported that focal point velocities for brook trout fry in Idaho ranged from 8-10 cm/sec, with a maximum of 16 cm/sec. Because brook trout fry occupy the same stream reaches as adults, we assume that temperature and dissolved oxygen requirements for brook trout fry are similar to those for adults.

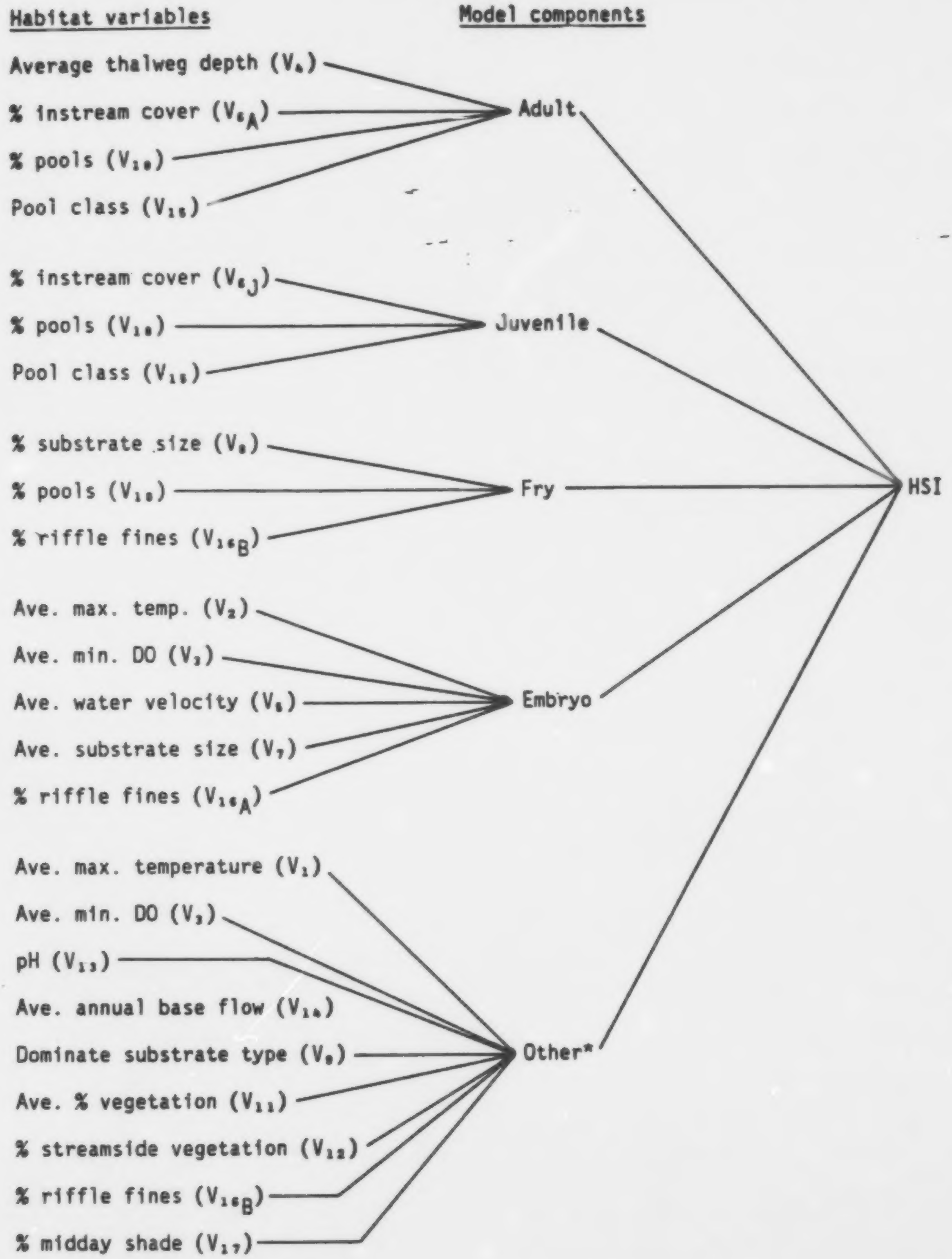
Trout fry usually overwinter in shallow areas of low velocity, with rubble being the principal cover (Everest 1969; Bustard and Narver 1975a). Optimum size of substrate used as winter cover by steelhead fry and small juveniles ranges from 10-40 cm in diameter (Hartman 1965; Everest 1969). A relatively silt-free area of substrate of this size class (10-40 cm), ≥ 10% of the total habitat, will probably provide adequate cover for brook trout fry and small juveniles. The use of smaller diameter rocks for winter cover may result in increased mortality due to shifting of the substrate (Bustard and Narver 1975a).

Juvenile. Davis (1961) stated that temperatures of 11-14° C are optimum for fingerling growth. Griffith (1972) reported focal point velocities for juvenile brook trout that ranged from 8.0-9.0 cm/sec, with a maximum of 24 cm/sec. We assume that temperature and dissolved oxygen requirements for juvenile brook trout are similar to those for adults.

Wesche (1980) reported that brook trout fry and small juveniles < 15 cm long were associated more with instream cover objects (rubble substrate) than overhead stream bank cover. An area of cover ≥ 15% of the total stream area appears adequate for juvenile brook trout.

HABITAT SUITABILITY INDEX (HSI) MODELS

Figure 1 depicts the theoretical relationships among model variables, components, and HSI for the brook trout model.


Habitat variables
Model components
Average thalweg depth (V_4)
% instream cover (V_{6_A})
% pools (V_{10})
Pool class (V_{15})
Adult
% instream cover (V_{6_J})
% pools (V_{10})
Pool class (V_{15})
Juvenile
% substrate size (V_8)
% pools (V_{10})
% riffle fines (V_{16_B})
Fry
Ave. max. temp. (V_2)
Ave. min. DO (V_3)
Ave. water velocity (V_5)
Ave. substrate size (V_7)
% riffle fines (V_{16_A})
Embryo
Ave. max. temperature (V_1)
Ave. min. DO (V_3)
pH (V_{13})
Ave. annual base flow (V_{14})
Dominate substrate type (V_9)
Ave. % vegetation (V_{11})
% streamside vegetation (V_{12})
% riffle fines (V_{16_B})
% midday shade (V_{17})
Other*
HSI

*Variables that affect all life stages.

Figure 1. Diagram illustrating the relationships among model variables, components, and HSI.

Model Applicability

Geographic area. The following model is applicable over the entire range of brook trout distribution. Where differences in habitat requirements have been identified for different races of brook trout, suitability index graphs have been constructed to reflect these differences. For this reason, care must be excercised in use of the individual graphs and equations.

Season. The model rates the freshwater habitat of brook trout for all seasons of the year.

Cover types. The model is applicable to freshwater riverine or lacustrine habitats.

Minimum habitat area. Minimum habitat area is the minimum area of contiguous habitat that is required for a species to live and reproduce. Because brook trout can move considerable distances to spawn or locate suitable summer or winter rearing habitat, no attempt has been made to define a minimum habitat size for the species.

Verification level. An acceptable level of performance for this brook trout model is for it to produce an index between 0 and 1 that the authors and other biologists familiar with brook trout ecology believe is positively correlated with the carrying capacity of the habitat. Model verification consisted of testing the model outputs from sample data sets developed by the author to simulate high, medium, and low quality brook trout habitat and model review by biologists familiar with brook trout ecology.

Model Description - Riverine

The riverine HSI model consists of five components: Adult (C_A); Juvenile (C_J); Fry (C_F); Embryo (C_E); and Other (C_O). Each life stage component contains variables specifically related to that component. The component C_O contains variables related to water quality and food supply that affect all life stages of brook trout.

The model utilizes a modified limiting factor procedure. This procedure assumes that model variables and components with suitability indices in the average to good range, > 0.4 to < 1.0, can be compensated for by higher suitability indices of other, related model variables and components. However, variables and components with suitabilities ≤ 0.4 cannot be compensated for and, thus, become limiting factors on habitat suitability.

Adult component. Variable V_8, percent instream cover, is included because standing crops of adult trout have been shown to be correlated with the amount of cover available. Percent pools (V_{10}) is included because pools provide cover and resting areas for adult trout. Variable V_{10} also quantifies the amount of pool habitat that is needed. Variable V_{15}, pool class, is included because pools differ in the amount and quality of escape cover, winter cover, and resting areas that they provide. Average thalweg depth (V_4) is included because average water depth affects the amount and quality of pools and instream cover available to adult trout and migratory access to spawning and rearing areas.

Juvenile component. Variables V_6, percent instream cover; V_{10}, percent pools; and V_{15}, pool class are included in the juvenile component for the same reasons listed above for the adult component. Juvenile brook trout use these essential stream features for escape cover, winter cover, and resting areas.

Fry component. Variable V_8, percent substrate size class, is included because trout fry utilize substrate as escape cover and winter cover. Variable V_{10}, percent pools, is included because fry use the shallow, slow water areas of pools and backwaters as resting and feeding stations. Variable V_{16}, percent fines, is included because the percent fines affects the ability of the fry to utilize the rubble substrate for cover.

Embryo component. It is assumed that habitat suitability for trout embryos depends primarily on water temperature, V_2; dissolved oxygen content, V_3; water velocity, V_5; spawning gravel size, V_7; and percent fines, V_{16}. Water velocity, V_5; gravel size, V_7; and percent fines, V_{16}, are interrelated factors that affect the transport of dissolved oxygen to the embryo and the removal of the waste products of metabolism from the embryo. These functions have been shown to be vital to the survival of trout embryos. In addition, the presence of too many fines in the redds will block movement of the fry from the incubating gravels to the stream.

Other component. This component contains model variables for two subcomponents, water quality and food supply, that affect all life stages. The subcomponent water quality contains four variables: maximum temperature (V_1); minimum dissolved oxygen (V_3); pH (V_{13}); and base flow (V_{14}). All four variables affect the growth and survival of all life stages except embryo, whose water quality requirements are included with the embryo component. The subcomponent food supply contains three variables: substrate type (V_9); percent vegetation (V_{11}); and percent fines (V_{16}). Dominant substrate type (V_9) is included because the abundance of aquatic insects, an important food item for brook trout, is correlated with substrate type. Variable V_{16}, percent fines in riffle-run and spawning areas, is included because the presence of excessive fines in riffle-run areas reduces the production of aquatic insects. Variable V_{11} is included because allochthonous materials are an important source of nutrients to cold, unproductive trout streams. The waterflow of all streams fluctuate on an annual seasonal cycle. A correlation exists between the average annual daily streamflow and the annual low base flow period in maintaining desirable stream habitat features for all life stages. Variable V_{14} is included to quantify the relationship between annual water flow fluctuations and trout habitat suitability.

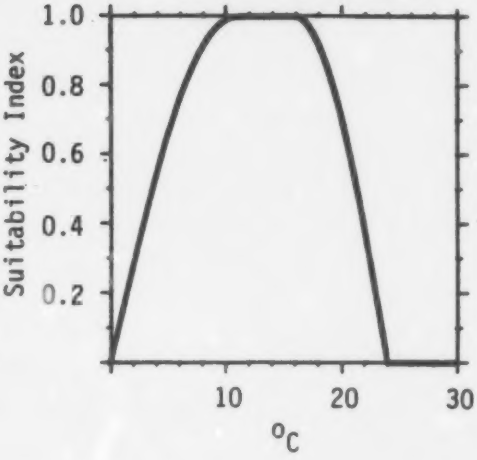
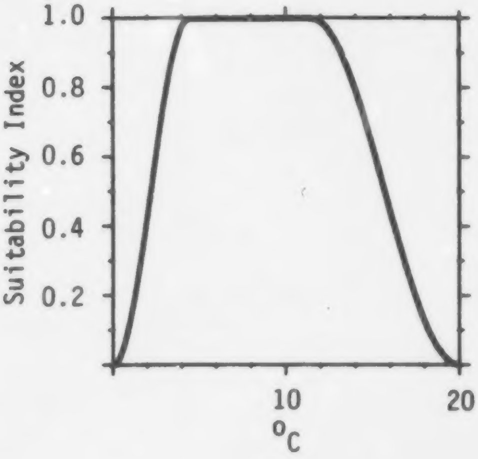
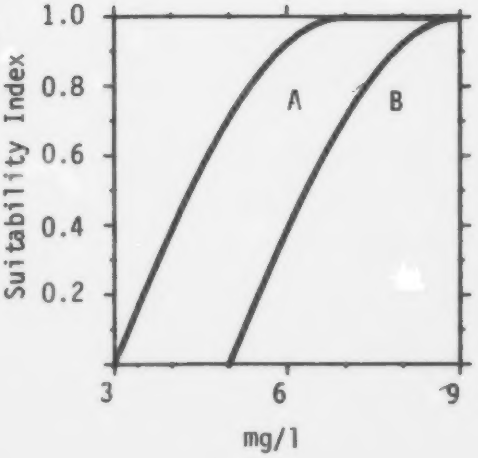
Variables V_{11}, V_{12}, and V_{17} are optional variables to be used only when needed and appropriate. Average percent vegetation for nutrient supply, V_{11}, should be used only on small (< 50 m wide) streams with summer temperatures > 10° C. Percent streamside vegetation, V_{12}, is included because streamside vegetation is an important means of controlling soil erosion, a major source of fines in streams. Variable V_{17}, percent midday shade, is included because the amount of shade can affect water temperature and photosynthesis in streams. Variables V_{11}, V_{12}, and V_{17} are used primarily for streams ≤ 50 m wide with temperature, photosynthesis, or erosion problems or when changes in the riparian vegetation is part of a potential project plan.

Suitability Index (SI) Graphs for Model Variables

This section contains suitability index graphs for 17 model variables. Equations and instructions for combining groups of variable SI scores into component scores and component scores into brook trout HSI scores are included.

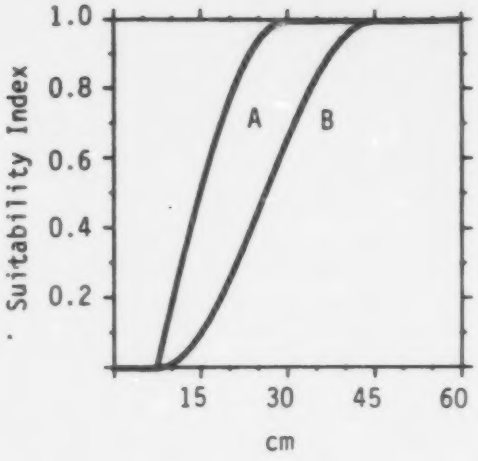
The graphs were constructed by quantifying information on the effect of each habitat variable on the growth, survival, or biomass of brook trout. The curves were built on the assumption that increments of growth, survival, or biomass originally plotted on the y-axis of the graph could be directly converted into an index of suitability from 0.0 to 1.0 for the species; 0.0 indicates unsuitable conditions and 1.0 indicates optimum conditions. Graph trend lines represent the author's best estimate of suitability for the various levels of each variable presented. The graphs have been reviewed by biologists familiar with the ecology of the species, but obviously some degree of SI variability exists. The user is encouraged to vary the shape of the graphs when existing regional information indicates a different variable suitability relationship.

The habitat measurements and SI graph construction are based on the premise that extreme, rather than average, values of a variable most often limit the carrying capacity of a habitat. Thus, measurement of extreme conditions, e.g., maximum temperatures and minimum dissolved oxygen levels, are often the data used with the graphs to derive the SI values for the model. The letters R and L in the habitat column identify variables used to evaluate riverine (R) or lacustrine (L) habitats.

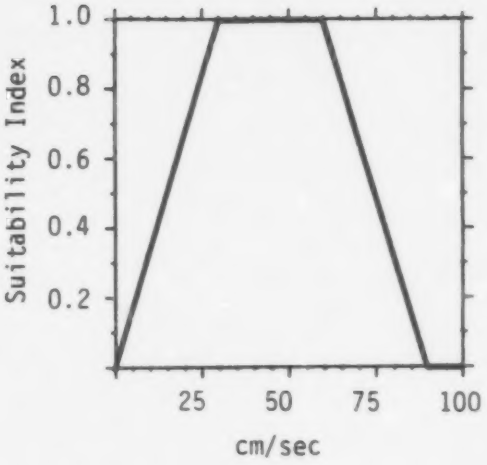
Habitat	Variable		Suitability graph
R,L	V_1	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). For lacustrine habitats, use temperature strata nearest optimum in dissolved oxygen zones of > 3 mg/l.	
R	V_2	Average maximum water temperature (°C) during embryo development.	
R,L	V_3	Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo). For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimum where dissolved oxygen is > 3 mg/l. A = ≤ 15° C B = > 15° C	

R V_4 Average thalweg depth (cm) during the late growing season low water period.

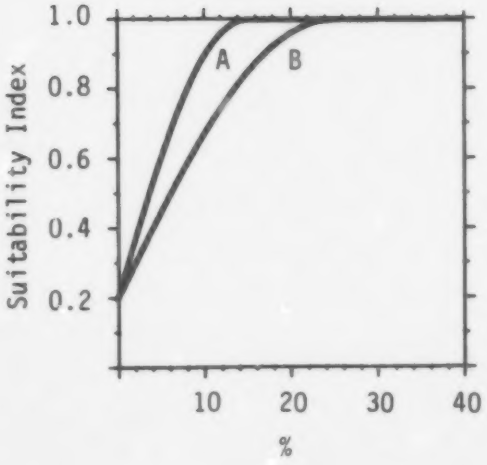
A = stream width ≤ 5 m
B = stream width > 5 m



R V_5 Average velocity (cm/sec) over spawning areas during embryo development.



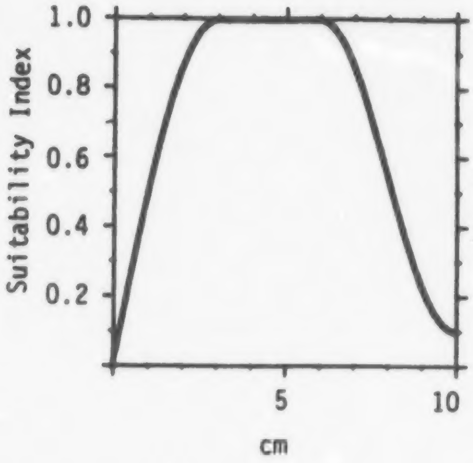
R V_6 Percent instream cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.
A = Juveniles
B = Adults



R V_7

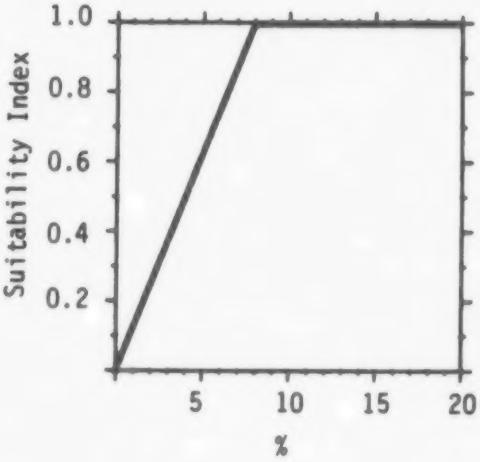
Average size of substrate between 0.3-8 cm diameter in spawning areas, preferably during the spawning period.

To derive an average value for use with graph V_7, include areas containing the best spawning substrate sampled until all potential spawning sites are included or the sample contains an area equal to 5% of the total brook trout habitat being evaluated.



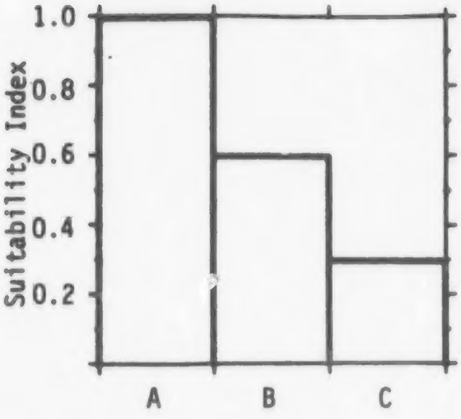
R V_8

Percent substrate size class (10-40 cm) used for winter and escape cover by fry and small juveniles.

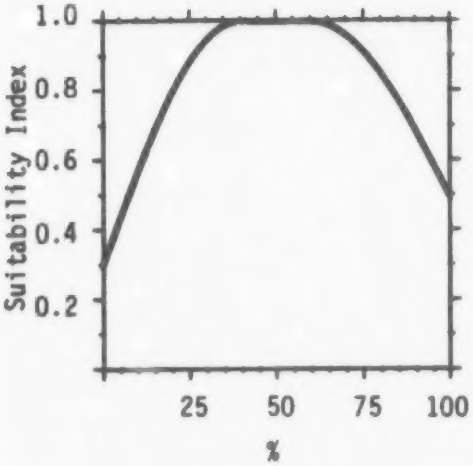


R V_9 Dominant (≥ 50%) substrate type in riffle-run areas for food production.

A) Rubble or small boulders or aquatic vegetation in spring areas dominant, with limited amounts of gravel, large boulders, or bedrock.
B) Rubble, gravel, boulders, and fines occur in approximately equal amounts or gravel is dominant. Aquatic vegetation may or may not be present.
C) Fines, bedrock, or large boulders are dominant. Rubble and gravel are insignificant (≤ 25%).



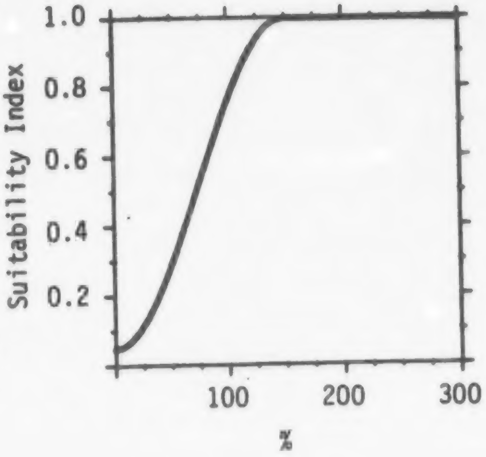
R V_{10} Percent pools during the late growing season low water period.



R V_{11} Optional

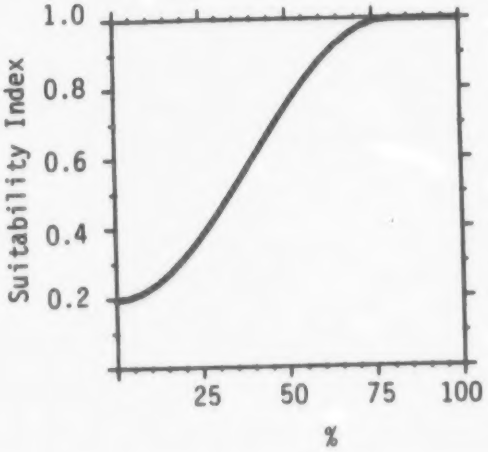
Average percent vegetation (trees, shrubs, and grasses-forbs) along the streambank during the summer for allochthonous input. Vegetation Index = 2 (% shrubs) + 1.5 (% grasses) + (% trees) + 0 (% bareground).

(For streams ≤ 50 m wide)



R V_{12} Optional

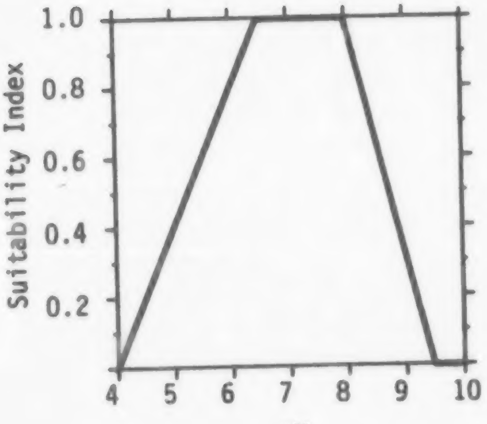
Average percent rooted vegetation and stable rocky ground cover along the streambank during the summer (erosion control).



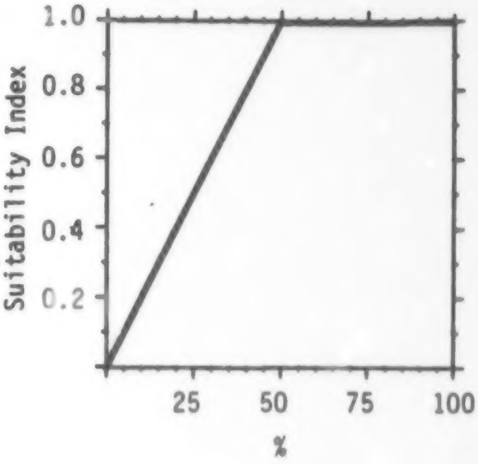
R,L V_{13}

Annual maximal or minimal pH. Use the measurement with the lowest SI value.

For lacustrine habitats, measure pH in the zone with the best combination of dissolved oxygen and temperature.



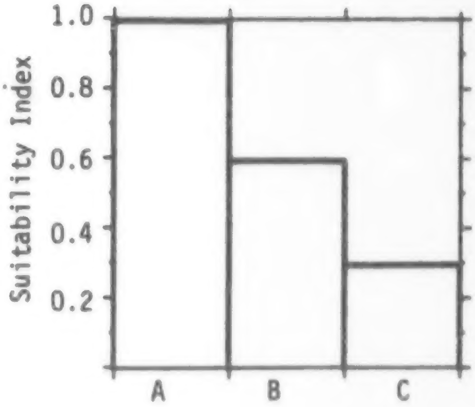
R V_{14} Average annual base flow regime during the late summer or winter low flow period as a percent of the average annual daily flow.



R V_{15} Pool class rating during the late growing season low flow period (Aug-Oct). The rating is based on the percent of the area containing pools of the three classes described below.

A) ≥ 30% of the area is comprised of first-class pools.
B) ≥ 10% but < 30% first-class pools or ≥ 50% second-class pools.
C) < 10% first-class pools and < 50% second-class pools.

(See pool class descriptions below)



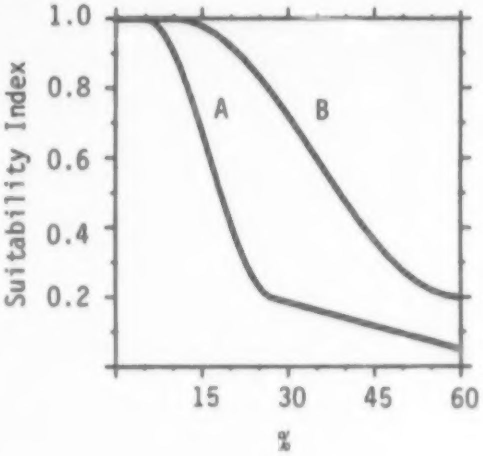
A) First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscured due to depth, surface turbulence, or the presence of structures, e.g., logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

B) Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscured due to surface turbulence, depth, or the presence of structures. Typical second-class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

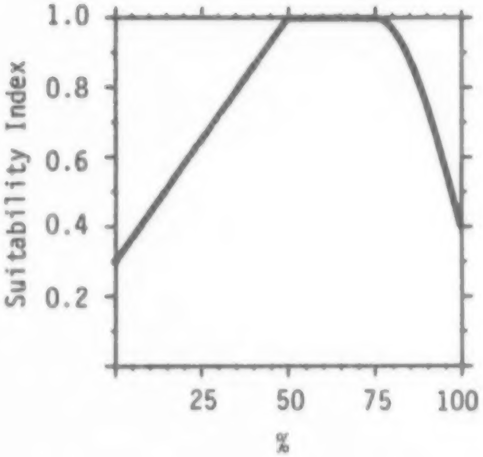
C) Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structures. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders.

R V_{16} Percent fines (< 3 mm) in riffle-run and in spawning areas during average summer flows.

A = Spawning
B = Riffle-run



R V_{17} Optional Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use on cold (< 16° C max. temp.), unproductive streams.



References to sources of data and the assumptions used to construct the above suitability index graphs for brook trout HSI models are presented in Table 1.

Table 1. Data sources for brook trout suitability indices.

	Variable and source	Assumption
V_1	Bean 1909 Embody 1921 Kendall 1924 Baldwin 1951 Brasch et al. 1958 Mullen 1958 Davis 1961 McAfee 1966 MacCrimmon & Campbell 1969 Hynes 1970	Average maximum daily temperatures have a greater effect on trout growth and survival than minimum temperature.
V_2	Embody 1934 Smith 1947 Brasch et al. 1958 MacCrimmon & Campbell 1969	The average maximum daily water temperature during embryo development related to the highest survival of embryos and normal development is optimum.
V_3	Embody 1927 Fry 1951 Doudoroff & Shumway 1970 Mills 1971 Trojnav 1972 Sekulich 1974 Harshbarger 1975	The average minimum daily dissolved oxygen level during embryo development and the late growing season that is related to the greatest growth and survival of brook trout and trout embryos is optimum. Levels that reduce survival and growth are suboptimum.
V_4	Delisle and Eliason 1961 Estimated by authors	The average thalweg depths that provide the best combination of pools, instream cover, and instream movement of adult trout is optimum.
V_5	Thompson 1972 Hooper 1973 Hunter 1973 Reiser and Wesche 1977	The average velocity over the spawning areas affects the dissolved oxygen concentration and the manner in which waste products are removed from the developing embryos. Average velocities that result in the highest survival of embryos are optimum. Velocities that result in reduced survival are suboptimum.

Table 1 (continued).

Variable and source		Assumption
V_6	Boussu 1954 Elser 1968 Lewis 1969	Trout standing crops are correlated with the amount of usable cover present. Usable cover is associated with water $\geq$ 15 cm deep and velocities $\leq$ 15 cm/sec. These conditions are associated more with pool than riffle conditions. The best ratio of habitat conditions is about 50% pool to 50% riffle areas. Not all of a pool's area provides usable cover. Thus, it is assumed that optimum cover conditions for trout streams are reached at < 50% of the total area.
V	Bjornn 1971 Phillips et al. 1975 Duff 1980	The average size of spawning gravel that is correlated with the best water exchange rates, proper redd construction, and highest fry survival is assumed to be optimum for average-sized brook trout. The percentage of total spawning area needed to support a good trout population was calculated from the following assumptions: 1. Excellent riverine trout habitat will support about 500 kg/hectare. 2. Spawners comprise about 80% of the weight of the population. 500 kg x 80% = 400 kg of spawners. 3. Brook trout adults average about 0.2 kg each $\frac{400 \text{ kg}}{0.2 \text{ kg}}$ = 2,000 adult spawners 4. There are two adults per redd $\frac{2{,}000}{2}$ = 1,000 pairs 5. Each redd covers $\geq 0.5 \text{ m}^2$ $1{,}000 \times 0.5 \geq 500 \text{ m}^2$

Table 1 (continued).

Variable and source		Assumption
		6. There are 10,000 m^2 per hectare $\frac{500}{10,000}$ = 5% of total area
V_8	Hartman 1965 Everest 1969 Bustard and Narver 1975a	The substrate size range selected for escape and winter cover by brook trout fry and small juveniles is assumed to be optimum.
V_9	Pennak and Van Gerpen 1947 Hynes 1970	The dominant substrate type containing the greatest numbers of aquatic insects is assumed to be optimum for insect production.
V_{10}	Needham 1940 Elser 1968 Hunt 1971	The percent pools during late summer low flows that is associated with the greatest trout abundance is optimum.
V_{11}	Idyll 1942 Delisle and Eliason 1961 Chapman 1971 Hunt 1975	The average percent vegetation along the streambank is related to the amount of allochthanous materials deposited annually in the stream. Shrubs are the best source of allochthanous materials, followed by grasses and forbs, and then trees. The vegetational index is a reasonable approximation of optimum and suboptimum conditions for most trout stream habitats.
V_{12}	Anonymous 1979 Raleigh and Duff 1981	The average percent rooted vegetation and rocky ground cover that provides adequate erosion control to the stream is optimum.
V_{13}	Creaser 1930 Parsons 1968 Dunson & Martin 1973 Daye & Garside 1975 Webster 1975 Menendez 1976	The average annual maximum or minimum pH levels related to high survival of trout are optimum.

Table 1 (concluded).

Variable and source		Assumption
V_{14}	Binns 1979 Adapted from Duff and Cooper 1976	Flow variations affect the amount and quality of pools, instream cover, and water quality. Average annual base flows associated with the highest standing crops are optimum.
V_{15}	Needham 1940 Lewis 1969 Hunt 1976	Pool classes associated with the highest standing crops of trout are optimum.
V_{16}	Cordone & Kelly 1961 Bjornn 1969 Sykora et al. 1972 Platts 1974 Phillips et al. 1975	The percent fines associated with the highest standing crops of food organisms, embryos, and fry in each designated area is optimum.
V_{17}	Sabean 1976, 1977 Anonymous 1979	The percent of stream area that is shaded that is associated with optimum water temperatures and photosynthesis rates is optimum.

The above references include data from studies on related salmonid species. This information has been selectively used to supplement, verify, or complete data gaps on the habitat requirements of brook trout.

The suitability curves are a compilation of published and unpublished information on brook trout. Information from other life stages or species or expert opinion was used to formulate curves when data for a particular habitat parameter or life stage were insufficient. Data are not sufficient at this time to refine the habitat suitability curves that accompany this narrative to reflect subspecific or regional differences. Local knowledge should be used to regionalize the suitability curves if that information will yield a more precise suitability index score. Additional information on this species that can be used to improve and regionalize the suitability curves should be forwarded to the Habitat Evaluation Group, U.S.D.I. Fish and Wildlife Service, 2625 Redwing Road, Fort Collins, CO 80526.

Riverine Model

This model uses a life stage approach with five components: adult; juvenile; fry; embryo; and other.

Adult (C_A). C_A variables: V_4; V_6; V_{10}; and V_{15}

Case 1: Where V_6 is $> (V_{10} \times V_{15})^{1/2}$;

$$C_A = [V_4 \times V_6 (V_{10} \times V_{15})^{1/2}]^{1/3}$$

Case 2: Where V_6 is $\leq (V_{10} \times V_{15})^{1/2}$;

$$C_A = [V_4 (V_{10} \times V_{15})^{1/2}]^{1/2}$$

If V_4 or $(V_{10} \times V_{15})^{1/2}$ is ≤ 0.4 in either equation, then C_A = the lowest score.

Juvenile (C_J). C_J variables: V_6; V_{10}; and V_{15}

$$C_J = \frac{V_6 + V_{10} + V_{15}}{3}$$

Or, if any variable is ≤ 0.4, C_J = the lowest variable score.

Fry (C_F). C_F variables: V_8; V_{10}; and V_{16}

$$C_F = [V_{10} (V_8 \times V_{16})^{1/2}]^{1/2}$$

Or, if V_{10} or $(V_8 \times V_{16})^{1/2}$ is ≤ 0.4, C_F = the lowest factor score.

Embryo (C_E). C_E variables: V_2; V_3; V_6; V_7; and V_{16}

Steps:

A. A potential spawning site is an ≥ 0.5 m² area of gravel, 0.3-8.0 cm in size, covered by flowing water ≥ 15 cm deep. At each spawning site sampled, record:

1. The average water velocity over the site;
2. The average size of all gravel between 0.3-8.0 cm;
3. The percent fines < 0.3 cm in the gravel; and
4. The total area in m² of each site.

B. Derive a spawning site suitability index (V_s) for each site by combining V_6, V_7, and V_{16} values follows:

$$V_s = (V_6 \times V_7 \times V_{16})^{1/3}$$

C. Derive a weighted average ($\overline{V}_s$) for all sites included in the sample.

Select the best V_s scores until all sites are included, or until brook trout habitat has been included, whichever comes first.

$$\overline{V}_s = \frac{\sum_{i=1}^{n} A_i V_{si}}{\text{total habitat area}} / 0.05 \text{ (output cannot > 1.0)}$$

where A_i = the area of each spawning site in m² (ΣA_i cannot exceed 5% of the total brook trout habitat).

V_{si} = the individual SI scores from the best spawning areas until all spawning sites have been included or until SI's from an area equal to 5% of the total brook trout habitat being evaluated has been included, whichever occurs first.

D. Derive C_E

C_E = the lowest score of V_2, V_3, or $\overline{V}_s$

Other (C_O). C_O variables: V_1; V_3; V_9; V_{11}; V_{12}; V_{13}; V_{14}; V_{16}; and V_{17}

$$C_O = \left[\frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2} \times (V_1 \times V_3 \times V_{12} \times V_{13} \times V_{14} \times V_{17})^{1/N} \right]^{1/2}$$

where N = the number of variables within the parentheses. Note that variables V_{11}, V_{12} and V_{17} are optional and, therefore, can be omitted.

HSI determination. HSI scores can be derived for a single life stage, a combination of two or more life stages, or all life stages combined. In all cases, except for the embryo component (C_E), an HSI is obtained by combining one or more life stage component scores with the other component (C_O) score.

1. Equal Component Value Method. The equal component value method assumes that each component exerts equal influence in determining the HSI. This method should be used to determine the HSI unless information exists that individual components should be weighted differently. Components: C_A; C_J; C_F; C_E; and C_O.

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_O)^{1/N}$$

Or, if any component is ≤ 0.4, the HSI = the lowest component value; if C_A is < the equation value, the HSI = C_A.

wnere N = the number of components in the equation.

Solve the equation for the number of components included in the evaluation. There will be a minimum of two, one or more life stage components and the component (C_O), unless only the embryo life stage (C_E) is being evaluated, in which case the HSI = C_E.

2. Unequal Component Value Method. This method also uses a life stage approach with five components: adult (C_A); juvenile (C_J); fry (C_F); embryo (C_E); and other (C_O). However, the C_O component is divided into two subcomponents, food (C_{OF}) and water quality (C_{OQ}). It is assumed that the C_{OF} subcomponent can either increase or decrease the suitability of the habitat by its effect on growth at each life stage except embryo.

The C_{OQ} subcomponent is assumed to exert an influence equal to the combined influence of all other model components in determining habitat suitability. The method also assumes that water quality is excellent, $C_{OQ} = 1$. When C_{OQ} is < 1, the HSI is decreased. In addition, when a basis for weighting exists, model component and subcomponent weights can be increased by multiplying each index value by multipliers > 1. Model weighting procedures must be documented.

Components and subcomponents: C_A; C_J; C_F; C_E; C_{OF}; and C_{OQ}

Steps:

A. Calculate the subcomponents (C_{OF} and C_{OQ}) of C_O

$$C_{OF} = \frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2}$$

$$C_{OQ} = (V_1 \times V_3 \times V_{13} \times V_{14})^{1/4}$$

Or, if any variable is ≤ 0.4, C_{OQ} = the value of the lowest variable.

B. Calculate the HSI by either the noncompensatory or the compensatory option.

Noncompensatory option. This option assumes that degraded water quality conditions cannot be compensated for by good physical habitat conditions. This assumption is most likely true for small streams (≤ 5 m wide) and for persistent degraded water quality conditions.

$$HSI = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N} \times C_{OQ}$$

where N = the number of components and subcomponents inside the parentheses or, if the model components or subcomponents have unequal weights, N = Σ of weights selected.

Or, if any component is ≤ 0.4, HSI = the lowest component value x C_{OQ}.

If only the embryo component is being evaluated, $HSI = C_E \times C_{OQ}$.

Compensatory option. This method assumes that moderately degraded water quality conditions can be partially compensated for by good physical habitat conditions. This assumption is useful for large rivers (≥ 50 m wide) and for temporary, or short term, poor water quality conditions.

1) $HSI' = (C_A \times C_J \times C_F \times C_E \times C_{OF})^{1/N}$

where N = the number of components and subcomponents in the equation or, if the model components or subcomponents have unequal weights, $N = \Sigma$ of weights selected.

Or, if C_A is ≤ 0.4, the $HSI' = C_A$

2) If C_{OQ} is $< HSI'$, $HSI =$ the $HSI' \times [1 - (HSI' - C_{OQ})]$; if $C_{OQ} \geq HSI'$, the $HSI = HSI'$.

3) If only the embryo component is being evaluated, follow the procedure in step 2, substituting C_E for HSI'.

Lacustrine Model

The following model can be used to evaluate brook trout lacustrine habitat. The lacustrine model consists of two components: water quality and reproduction.

Water Quality (C_{WQ}). C_{WQ} variables: V_1; V_3; and V_{13}

$$C_{WQ} = (V_1 \times V_3 \times V_{13})^{1/3}$$

Or, if the SI scores for V_1 or V_3 are ≤ 0.4, C_{WQ} = the lowest SI score for V_1 or V_3.

Note: Lacustrine brook trout can spawn in spring upwelling areas of lacustrine habitats but will utilize tributary streams for spawning and embryo development when available and suitable. If the embryo life stage riverine habitat is included in the evaluation, use the embryo component steps and equations in the riverine model above, except that the area of spawning gravel needed is only about 1% of the total surface area of the lacustrine habitat.

Embryo (C_E). C_E variables: V_2; V_3; V_5; V_7; and V_{16}

$$\bar{V}_s = \frac{\sum_{i=1}^{n} A_i \, V_{si}}{\text{total habitat area}} / 0.01 \text{ (output cannot > 1.0)}$$

HSI determination.

$$HSI = (C_{WQ} \times C_E)^{1/2}$$

If only the lacustrine habitat is evaluated, the HSI = C_{WQ}.

Interpreting Model Outputs

Model HSI scores for individual life stages, composite life stages, or for the species are a relative indicator of habitat suitability. The HSI models, in their present form, are not intended to reliably predict standing crops of fishes throughout the United States. Standing crop limiting factors, such as interspecific competition, predation, disease, water nutrient levels, and length of growing season, are not included in the aquatic HSI models. The models contain physical habitat variables important in maintaining viable populations of brook trout. If the model is correctly structured, a high HSI score for a habitat indicates near optimum regional conditions for brook trout for those factors included in the model, intermediate HSI scores indicate average habitat conditions, and low HSI scores indicate poor habitat conditions. An HSI of 0 does not necessarily mean that the species is not present; it does indicate that the habitat is very poor and that the species is likely to be scarce or absent.

Brook trout tend to occupy riverine habitats where very few other fish species are present. They are usually competitively excluded by other salmonid species, except cutthroat. Thus, disease, interspecific competition, and predation usually have little affect on the model. When the brook trout model is applied to brook trout streams with similar water quality and lengths of growing season, it should be possible to calibrate the model output to reflect size of standing crops within some reasonable confidence limits. This possibility, however, has not been tested with the present model.

Sample data sets selected by the author to represent high, intermediate, and low habitat suitabilities are in Table 2, along with the SI's and HSI's generated by the brook trout riverine model. The model outputs calculated from the sample data sets (Tables 3 and 4) reflect what I believe carrying capacity trends would be in riverine habitats with the listed characteristics.

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FILMED

CARTES
OMISES